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Report on Geneva

This report on the International Conference on the Peaceful Uses of Atomic Energy, held at Geneva from August 8 to August 20, 1955, is based on lectures, papers, various publications, and personal observations. After stressing the need for a new source of energy and outlining the basic principles and types of nuclear reactors, this instalment deals with power reactors actually in operation and those in the blue-print stage or under construction. Subsequent instalments will discuss research reactors, radioisotopes, etc.

THERE has been a strikingly steady upward trend of about 2% per annum in the world consumption of the conventional fuels. The differences between countries in their *per capita* incomes are closely related to the differences between them in fuel consumption, and the growth of the latter is closely linked to, but not as fast as, the growth in industrial activity.

It is hard to assess what reserves of fuel remain in the ground and harder still to measure the amount it will be feasible to extract, because the latter is a function of economics and mining technique, as well as of geology. There is, however, a long-term tendency for the price of coal to rise more rapidly than wholesale prices generally. Also significant is the extent to which an increasing proportion of primary fuel is converted into electricity before it is supplied to the ultimate consumer. The reserves of the conventional fuels are, of course, finite and, despite any probable discoveries of new resources, cannot sustain an indefinite increase in world population, productivity, and standards of living. What is of special interest is how soon they are likely, in the absence of a new source of energy, to limit the rate of further growth. The conclusion reached is that, even on the basis of the lowest reasonable estimates of the growth of demand, this date cannot be very far distant. By the end of this century, shortage of reserves is likely to have started to limit the consumption of oil and natural gas, and during the course of the next century the consumption of the remaining conventional fuels is likely to encounter similar limits.

The development of nuclear energy for power production is, therefore, beginning none too soon. This is particularly true if it is thought important to conserve some of the world's stocks of oil or coal for consumption by future generations for certain purposes for which they may remain more suitable. Of critical importance will be the relative costs of producing electricity at thermal and nuclear power stations. It would appear to be desirable that, by the end of the present century, a large proportion of world electricity production should be in nuclear stations.

BASIC PRINCIPLES AND TYPES OF NUCLEAR REACTORS

To the man in the street in any country, the coming of nuclear power will mean simply more electrical power, produced, as now, from turbo-generators, but using steam derived from nuclear reactors, instead of from coal- or oil-fired boilers.

The nuclear reactor is often referred to as an "atomic furnace." This is natural because its operating temperature is high, because uranium can be considered the fuel, and because the first direct product is steam. However, it differs from a furnace in that it needs no air and so can operate for years firmly enclosed in concrete or even under water. Once charged with fissionable material as fuel, the nuclear reaction proceeds automatically and needs only the proper controls to regulate the rate of energy production to the desired level.

There are many types of reactors, built for different purposes, and more than thirty of them are now in continuous operation in several countries. All of them, however, generate heat and are preliminary steps towards power production. They all operate on the same principles and all have five major features in common, as follows :—

The Core :—At the heart of the reactor is the small mass of the active, fissionable fuel, either U^{235} or plutonium, the atoms of which explode one by one when hit by a neutron. The fragments fly apart at very high speeds and carry most of the energy, which is released as heat. This reaction starts spontaneously. Once initiated, it continues, because two or three neutrons are also ejected from each exploding atomic nucleus, and some of these in turn cause the explosion of neighbouring nuclei of other atoms. This is the chain reaction, which feeds on its own energy and continues indefinitely, provided only that there are enough fissionable atomic nuclei on hand to maintain the sequence.

The Moderator :—The speed of the neutrons emitted in the explosion of an atom is extremely high, almost as high as that of light. Since the neutrons are electrically neutral, they are very penetrating at this velocity and easily escape from the core and even from the reactor. Those that do escape are, of course, lost and useless. For this reason a "moderator" is used to reduce their speed. When neutrons strike the moderator there is an elastic collision, they give part of their energy to the moderator, and bounce off at a reduced speed. At this lower velocity they are much more easily "captured" by the uranium atoms to continue the fission reaction.

Such elastic collisions are most effective in reducing the speed of the neutrons when the particle struck by the neutron is not much heavier than the neutron itself. The moderator must therefore be composed of a material whose atoms are small. The most effective moderator is heavy water, which can be separated from ordinary water only by a long and expensive process. Since large quantities are needed, it is as yet comparatively seldom used.

The usual moderator is graphite, and since graphite is also easily available in large quantities at relatively low cost, graphite blocks serve as the moderator in most nuclear reactors.

The Control Rods :—When properly arranged, the fission reaction continues automatically; no effort or attention is needed to maintain it. On the contrary, it must be kept from going too fast and too far. There must be some device for controlling its rate, for slowing it down, and even for stopping it entirely. This is very simply effected in a reactor by providing rods or sheets

of a material which stops and absorbs the neutrons striking it, without itself being altered or destroyed. Such materials are unusual, but two fairly common suitable metals are boron and cadmium. Of these, cadmium is the more practical. Reactors are therefore so built that cadmium rods can be inserted into the core from the outside and can be withdrawn or replaced at will. When fully in place they " steal " the neutrons emitted in the spontaneous fission of a few fuel atoms, thus keeping them from striking other uranium nuclei, and stopping the reaction from going further. As they are gradually withdrawn from the core, the chain reaction sets in and gathers speed. It can be maintained at any desired level by adjusting the position of the cadmium control rods and can be stopped almost instantly by inserting them to the full. As a safety measure, the controls are usually operated automatically by instruments which continually measure neutron flux.

The Coolant :—The primary product of the reactor is energy. It is released directly as two or three high-velocity fragments of each exploding uranium nucleus. They too collide with all the materials of the reactor and, because they are relatively massive, produce heat. They are thus stopped, gradually accumulate as chemical impurities in the core, and must eventually be removed. However, this heat must also be removed, if only to prevent the entire reactor from rising to an unmanageable temperature.

In the small and early reactors this was effected by circulating a blast of air through them. Some large reactors to-day use compressed gases such as carbon dioxide. In others, large quantities of water are circulated through the reactors in pipes to keep the temperature down. All this heat has been wasted in those reactors used primarily for the production of plutonium, for the manufacture of special isotopes, for the study of the effect of neutrons on construction materials, or for other research purposes.

A power industry based on nuclear energy must, of course, capture and use all this heat. It must be transferred from the interior of the reactor to a steam boiler or some other user of the heat. Air is not an efficient agent for gathering and then delivering heat. Water has the disadvantage that it boils at a relatively low temperature. A high-boiling liquid, such as mercury, is preferable, because it operates at a high temperature and can thus transport a large amount of heat in a small volume of liquid. An alloy of the less common metals, sodium and potassium, is now in favour for this purpose.

The coolant is thus not merely a protector to keep the reactor from getting too hot. It is the essential link between the reactor, which generates energy, and the power plant, which converts the energy into useful form.

The Shield :—One additional feature is essential to every nuclear reactor, although it is not an actual working part. This is the massive shielding that must surround it on all sides to protect personnel from the penetrating rays generated within. There are two dangers, i.e., the stray neutrons escaping at high speed in spite of every effort to retain and use them, and the gamma rays also generated in the nuclear fission. A shield of solid concrete, some seven feet thick, is therefore placed on all sides of every reactor. Somewhat less steel or lead may be used, but the absorption must be done by a massive wall of heavy atoms and cannot be done by anything less.

Of the many special types of reactors now operating, the first and still the most important is one in which power production is not the primary purpose but the nuclear reaction turning U^{238} into plutonium. This element does not exist in nature but, when made artificially from uranium, it is a fissionable nuclear fuel equal in value to U^{235}. The process is simple in theory :—The U^{238} nucleus absorbs a neutron from the disintegration of U^{235}, and becomes U^{239}, which automatically turns into plutonium. However, in practice, this requires careful management, to ensure that as many neutrons as possible from the U^{235} are absorbed by the U^{238}. Each U^{235} nucleus, on exploding, forms two or three neutrons (an average of 2·5). One of them must explode another U^{235} nucleus to maintain the reaction. If more fuel is to be produced than is consumed, the remaining one or two nuclei must both be effective in producing plutonium. This means avoiding all loss of neutrons and also careful use of the moderator, so that it will slow the neutrons down to just the velocity at which they are most likely to be captured by the U^{238} nuclei. As the plutonium accumulates in the core, thoroughly mingled with the uranium, there comes a time when the core must be removed for the chemical separation of the two, an operation of extreme lifficulty because of the intense radioactivity of the other nuclear fragments in the core.

Since the reactor for making plutonium generates heat, and any reactor designed for the production of heat and power can also produce plutonium, one of the most interesting and important reactors is one that combines the two—hence generates power for commercial use and at the same time produces plutonium. If it can produce one atom of plutonium for each of U^{235} used, it consumes in effect no fuel, for it replaces all that is used. In fact, such a reactor has been operated for three years by the U.S. Atomic Energy Commission and has been shown to produce more fuel than it uses. Since it " breeds " fuel, it is known as a breeder. Its value lies in the possibility of making and selling the valuable plutonium as a by-product of the power production, thereby reducing the cost of reactor operation and, eventually, the cost of nuclear power. Of course, the breeding consumes U^{238}, which must be replaced from time to time.

A large number of special reactors has been built as experiments. In one, the rods of uranium fuel are replaced by a solution of a salt of uranium (the sulphate or nitrate) in water, which thus combines the fuel and the moderator in a single " soup," cooled by water flowing through a coiled pipe in a steel pot. In another, the core and moderator are suspended in a pool of water 20 ft deep, to serve both as coolant and shield. In still another, a solution of uranium salts in water is used for all three purposes, i.e., as fuel, moderator, and coolant. Other variations use pure U^{235} in the core, or enrichments of natural uranium with different percentages of U^{235}, or finally natural uranium itself. One recent reactor uses beryllium as a moderator, in place of graphite or heavy water. One important reactor has the sole purpose of testing the effect of neutron bombardment at high temperature on various types of steel, zirconium, and other metals in a search for structural materials that will last longer or will withstand higher temperatures than are at present possible. One reactor is designed to produce an intense " neutron storm " for use in transforming common materials into their radioactive isotopes, to be used in medical and other research. All this indicates that the experimental period of reactor design is not yet over.

The enormous difficulty of choosing a proper path for reactor development is easily seen by estimating the number of conceivable reactor types. In Table I some of the choices which are more or less at the disposal of the reactor designer are listed.

TABLE I. CHOICES TO BE MADE IN REACTOR DESIGN

Fuel	Fertile Material	Neutron Energy	Coolant	Geometry	Moderator
U^{233} U^{235}	Thorium Uranium	Fast Resonance	Gas Liquid-metal	Heterogeneous Homogeneous	H_2O D_2O
Pu^{239}	—	Slow	H_2O D_2O Hydro-carbons, etc.		Be BeO C_n etc.

The above table by no means lists all possible choices; nevertheless, the total number of combinations in Table I gives no less than 900 possible reactors. Of course, not all of these are sensible; for example, a fast reactor could hardly be cooled with water. Even so, there are probably 100 combinations at least which are not obviously impracticable. The main objective in reactor development is likely to trace out of this welter of possibilities the dozen or so which are likely to succeed. Fortunately, nuclear considerations greatly reduce the number of possibilities. The slow neutron breeding cycle almost certainly requires U^{233}-Th; the fast neutron cycle can use either U^{233}-Th or Pu^{239}-U, but the latter has the nuclear advantage.

POWER REACTORS

Of the many different reactors constructed for various purposes, only three at present serve actually to produce power, though others are, of course, under development or construction. Of these three, one is in the American submarine "Nautilus," while the other two, descriptions of which follow, are respectively in the U.S.A. and Russia.

The Prototype Boiling-Water Power Reactor in the U.S.A.

In order to gain experience under conditions of an operating power plant, a test facility, consisting of a reactor with a heat rating of approximately 15,000 kW and the associated control equipment necessary for continuous operation, was constructed by the Argonne National Laboratory. Steam generated by this reactor is either vented to atmosphere or is delivered to a turbo-generator with an electrical rating of 3500 kW.

Since the problems connected with the life and fabrication of fuel elements are adequately under investigation in connection with other projects, the fuel elements for this reactor were made of materials which permitted the easiest construction. The material used was aluminium, which has been found to have adequate life for reactor use at temperatures well over 200° C. For this particular boiling reactor test facility, an operating pressure of 300 psi was chosen, leading to a fuel-element surface temperature of 215° C. The uranium used was enriched in U^{235} to about 90% and was incorporated in plates to provide the heating surfaces.

Each plate consists of a core of uranium-aluminium alloy jacketed on two sides with aluminium, 24 of these plates being assembled to form a box-type fuel-element sub-assembly. Because the formation of steam in the channels exerts considerable force on the plates, the unsupported span of the plate must be made fairly short. A cooling channel is 0·264 in. thick, 1·27 in. wide, and 26·8 in. long. In order to fit into the core support structure, the sub-assembly is fitted with a bottom extension and a top section. By changing the length of the top extension, the heated length of plate can be changed without affecting the clamping arrangement of the core structure. Also, it provides above the heated fuel plates a tube which, in operation, is filled with a mixture of steam and water and therefore tends to increase the circulation rate of water through the core. Several concentrations of uranium in the fuel plates are available. The lowest concentration provides 137 grams of U^{235}, and the highest 233 grams of U^{235}, per sub-assembly.

The heavily loaded fuel elements are used to adjust the void coefficient of the reactor. Placing heavily loaded elements at the periphery of the reactor increases the leakage and therefore can increase the negative void coefficient.

Since this is a test facility, it was necessary to make arrangements to permit complete change of not only the fuel elements but of the whole reactor core assembly, including the control rods. The reactor vessel is a

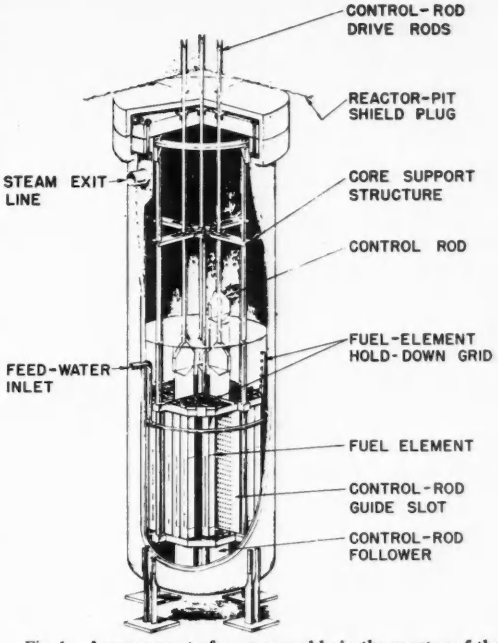

Fig. 1. **Arrangement of core assembly in the reactor of the prototype boiling-water power reactor.**

stainless-steel tank, 15 ft 11¼ in. high and 4 ft 4½ in. internal diameter, constructed of stainless-steel plate, ¾ in. thick. The core assembly is carried on a framework which is supported in the reactor vessel from a fixture which is bolted to the reactor vessel at the top, just below the flat lid closure. This construction permits removing the whole core assembly, even after the reactor has been operated and core materials have been activated. Fig. 1 is an illustration of the arrangement of the core assembly in the reactor vessel, while Fig. 2 is a cross-section through the core, giving the dimensions of the four blade-type control rods and the central cross control rod. Cadmium, boron, and hafnium are the absorbing materials in the control rods.

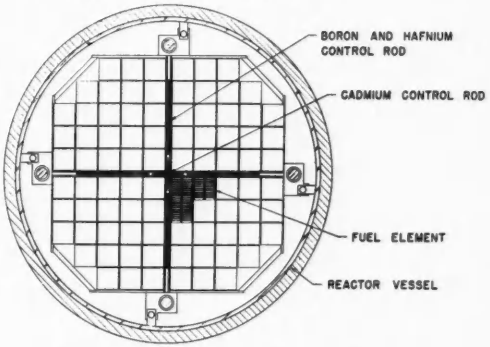

Fig. 2. **Cross-section through reactor core.**

The control-rod drives are situated above the dense concrete shield plug, which is rolled over the top of the reactor. In order to change fuel in the reactor, it is necessary to disconnect the control-rod drive rods, roll back the shield plug, and remove the lid of the reactor vessel. To make this possible, the reactor vessel and the

pit in which it stands are flooded with water. The insulation on the outside of the reactor vessel is of a type which does not deteriorate as a result of immersion in water.

The control-rod drives are so arranged that a control rod at any time can become a rapidly operating shutdown rod. A control rod which is driven by a shaft sealed through the wall of a pressure vessel such as this has two severe difficulties. Firstly, the internal pressure acts to lift the control rod out of the core, and, secondly, the friction of the packing gland opposes any motion of the rod. In the present design, the lifting force due to the steam pressure in the reactor vessel is balanced out with a steam cylinder and piston in which the drive rod terminates. Steam for the balancing cylinder is supplied from the reactor vessel.

A large force for moving the control rod is supplied by a pneumatic piston, which exerts a force of 800 lb to drive the rod. This is much larger than any friction force in the packing gland. When the rod is in use as a regulating rod, the pneumatic cylinder holds a stop on the drive shaft in contact with a large nut which straddles two lead screws, which are driven in synchronism. Driving the nut up or down imparts the same motion to the control rod. Rapid insertion of the control rod is achieved when the air pressure is switched to the side of the pneumatic cylinder which drives the rod down.

Fig. 3 is a flow diagram of the whole plant. Three principal circuits are indicated. The power circuit consists of a feed-water pump which can pump into the reactor either condensate returned from the condenser or freshly de-ionized water from the make-up system. The feed water is discharged into the annular downcomer of the reactor. This helps to cool the downcomer water and promotes the natural circulation in the reactor vessel. A large volume in the upper part of the reactor vessel contains only steam. This large volume promotes the separation of steam and water and acts as a cushion, preventing rapid pressure changes. Steam from the reactor vessel is carried by a 6-in. line either to the turbine or to a vent to the atmosphere. Valves suitable for these operations are shown. The condensate from the condenser is pumped to the feed-water tank.

The second circuit consists of a pump and electrical heaters. This permits pressurizing the reactor vessel without operation of the reactor. It is useful for testing for leaks and is also used to raise the temperature so that the reactor will not have to be run with the control rods inserted most of their length.

The third circuit is the clean-up circuit and consists of filters and ion-exchange columns. In operation these will become quite radioactive; consequently, they are installed in the fuel-element storage canal, so that the water of the canal will provide the necessary shielding. Fig. 4 shows the general arrangement of the equipment in the plant.

Since this facility is also used for transient testing of reactor cores, the control room is situated some distance from the reactor itself. All indication of operating conditions, therefore, must be made by electrical means. The level of the water in the reactor, which normally is about 4 ft above the active core, is closely controlled. Instruments for recording the level of the water are installed in a standpipe, exterior to the reactor vessel, and in the shielded pit which contains the pumps and other auxiliary equipment. Level control is by means of a float-type level controller installed at the operating level. A television camera is arranged so that the level in a sight glass can be read directly. The television camera also can be used to read directly a Bourdon-type pressure gauge, which measures the steam pressure in the reactor vessel. In the control room the rate of flow of feed-

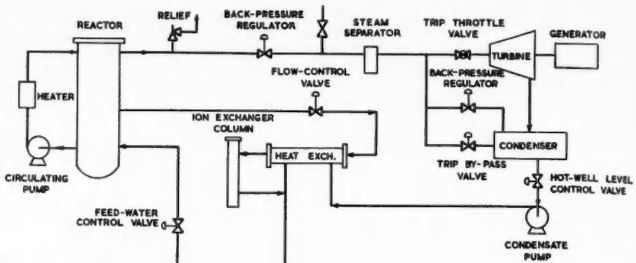

Fig. 3. **Flow diagram of complete plant.**

water, as well as the steam flow, is recorded.

Ionization chambers recording neutron flux are installed in tubes which extend close to the core, but outside the reactor vessel. Gamma-ray intensity at the top of the reactor vessel is recorded. The neutron intensity is measured by three types of instruments differing in their time constants. For normal operation, an amplifier recorder system, having a response time of 0·05 sec, is used. In order to observe transient effects, an amplifier recorder, with a time constant of 0·002 sec, or a galvanometer-oscillograph, with a time constant of 0·0004 sec, is used for neutron intensity.

It has been possible to operate the reactor under conditions which are stable for all pressures from atmospheric to 300 psi. A necessary requirement for reasonably smooth operation is that the amount of reactivity corresponding to the steam void should not be excessive. In all operations, however, the power level is subject to rapid variations. These clearly are connected with the turbulence created by the formation of steam. The degree of roughness of the power is directly related to the excess reactivity which has been subtracted by the formation of the steam voids and replaced by withdrawal of the control rods.

A series of experiments has been performed to determine the relationship between the excess reactivity in voids and the power density, and this has been carried out for a number of pressures. It has been observed that, for any given pressure, the degree of roughnses of the power varies with the excess reactivity in steam voids. If the excess reactivity is raised to too high a figure, oscillations in the power become apparent, and further increases in excess reactivity in steam may bring small excursions in the reactor power.

It is interesting to note the power level at which a typical fuel element operates. Assuming a power density of 22 kW/litre and a volume of 6·26 litres for the active section of a fuel element, the average fuel element delivers 138 kW. Fully loaded, the reactor contains 87 fuel elements (one fuel element is reserved for the installation of a start-up source), so that, at this power density, the total power is 12,000 kW. As the surface area of heated fuel plate in an element is 12,000 cm², the average heat flux is therefore 3 cal/cm² per sec, the maximum being about 7 cal/cm² per sec. It is clear that, in boiling reactors which employ only natural circulation of the water, the heat rates attained are not high. The limiting factor on power output is the rate of flow of steam out of the reactor core rather than the heat flux from the fuel plates. This characteristic is, of course, favourable from the standpoint of reactor safety; at the

same time, power densities in the range of 20 to 30 kW/litre of core (or 30 to 40 kW/litre of water in the core), which have been experimentally attained, are sufficiently large for many power-reactor applications.

The actual loading of the reactor is complicated by the fact that, for the experimental programme on attainable power densities, core sizes less than the maximum must be used, because the extra fuel allowance required for burn-up in continuous operation is not wanted. It is also complicated by the fact that the experiments must be performed either without appreciable xenon poison or with saturated xenon poison. Great care in loading has been used to avoid arriving at erroneous conclusions, because in one experiment the full height of the reactor was used, whereas in another the effective height was reduced by operating with the control rods partially inserted.

For continuous operation, where burn-up will steadily reduce the available excess reactivity, burn-up plates incorporating a certain amount of boron are affixed to the sub-assembly. The time interval between successive additions of fuel can be substantially increased by the use of such burnable poison plates.

Reactivity can safely be added to this boiling reactor in amounts which are dependent upon the pressure of operation. Experiments to-date indicate that at 300 psi, with a water-channel width of 0·324 in., steady power operation is obtained, even with 3·2% reactivity subtracted by the steam voids. Experiments at lower pressures clearly indicate that there is an amount of excess reactivity, above which instability sets in. This is not a matter of great concern, because, as more and more reactivity is added, the instability manifests itself by oscillations in the power level. These oscillations have a period of about 0·4 sec and, as successive amounts of reactivity are taken up by the steam voids, the amplitude grows. There is a considerable region of added excess reactivity where these oscillations are stable and can be made to increase in amplitude only by a further increase in reactivity.

Experiments have been performed in which reactivity has been added at a fixed rate by the withdrawal of the control rods. In one such experiment, at the start of the withdrawal of the control rods, the power level was 485 kW and the reactor pressure was 300 psi. In approximately 40 sec, 2·5% excess reactivity was added. The power level rose with an approximately 6·5-sec period and levelled off at 5400 kW without any indication of unstable operation.

For a boiling reactor which is producing steam at an appreciable rate, there has been considerable conjecture as to the consequences of a sudden closure of the steam exit line. A boiling reactor connected to a turbine would experience this if the trip throttle valve of the turbine should close. For a boiling reactor, sudden closure of the steam delivery line is not possible if a trip valve is arranged to by-pass the steam to the condenser in all cases when the trip throttle valve to the turbine closes. Nevertheless, it was thought worthwhile to perform experiments in which the steam delivery line was suddenly closed. In this case, the reactor was operating at 150 psi and at a power level of 1400 kW. In these circumstances, 2% reactivity had been subtracted by steam voids. Closing the valve initiated an increase in power, which then levelled off at a little over 3000 kW. As was expected, the pressure rose steadily, but no instability was introduced in the power by the sudden closure of the valve in the steam delivery line. This experiment was repeated a number of times and indicated that there is no particular hazard connected with this circumstance.

The behaviour of the reactor in those circumstances where the pressure for some reason is allowed to rise until the safety valves open has also been investigated. The safety relief valves in use for this experiment were set to open at slightly over 250 psi and closed again when the pressure had dropped approximately 20 psi. This caused no difficulty at all in operation. The relief valve would open, the pressure would fall, with a small corresponding fall in reactor power, and then, when the relief valve closed, the reactor power would readjust itself to approximately its initial value.

It is clear, however, that, if a relief valve is opened and allowed to remain open a considerable length of time, resulting in a large drop in pressure, the reactor power will also fall by a large amount. The volume of the steam voids in the vessel will increase materially and, as the temperature of the reactor water falls, the amount of excess reactivity subtracted by the void will steadily increase. This eventually should lead to unstable operation. In an experiment of this type, the reactor was operating at 2900 kW and at a pressure of 265 psi. Reactivity, amounting to 1·8%, had been subtracted by the steam voids. A control valve in the steam line was suddenly opened to atmosphere. The reactor power fell rather rapidly to a few hundred kilowatts. The reactor pressure decreased steadily and, when it had fallen to 190 psi, the control valve was closed rapidly. The reactor now had appreciably more reactivity to be subtracted by steam voids than it had initially. The power rose rapidly to a value in the neighbourhood of 3000 kW, a value corresponding to the new void situation. It should be noted that the additional reactivity which was required to be subtracted by the steam voids had been acquired because the temperature of the reactor had fallen. The reactor now stabilized at this new power level, but it was clear that it was not far from the power-oscillation situation described earlier. In other experiments, with a more vigorous blowdown of the reactor, the oscillation region

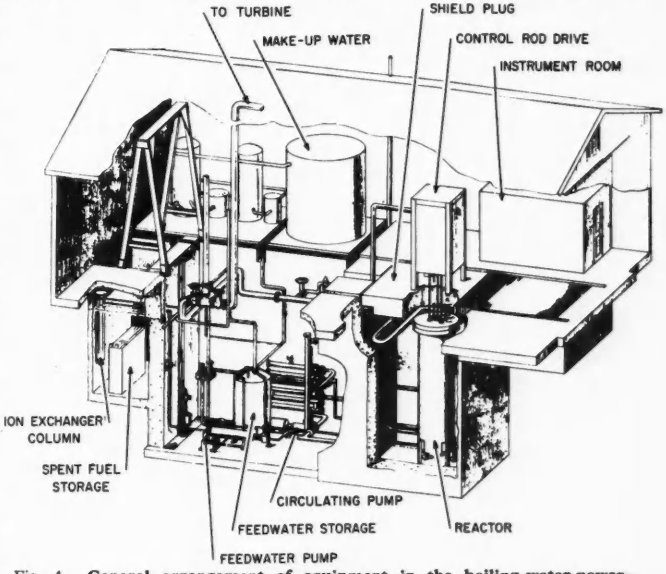

Fig. 4. **General arrangement of equipment in the boiling-water power-reactor building.**

actually was entered. These experiments indicate that in a boiling reactor any situation which causes a rapid decrease in reactor pressure should call for the immediate insertion of the shut-down rods. The shut-down does not have to be very fast because the flashing into steam of the moderator and the cooling of the reactor cannot be a very rapid event. It should, however, be a normal operating procedure to shut off the reactor whenever there is more than a predetermined decrease in reactor steam pressure.

The operation of a boiling reactor differs in a very marked manner from the operation of non-boiling reactors. In non-boiling reactors, the motion of the control rod ordinarily results in a change of power of the reactor with an exponential period. The amount of reactivity added by the motion of the rods must be judged carefully, in order to prevent short power periods which rather easily can produce temperature effects of a deleterious nature in the reactor. For the boiling reactor, addition of reactivity by the withdrawal of rods does not result in an exponential increase to another power level. The amounts of reactivity which can be added without undue concern for the boiling reactor are considerably greater than the amounts which can be treated in a similar way for a non-boiling reactor. It is only necessary to regulate the changes so that the region of oscillating instability is avoided. This has been very easy to effect during many hours of operation.

In practice, once the conditions of operation for the reactor have been established, the start-up of the reactor is as follows :—In order to avoid a situation where reactor power changes are introduced when the moderator is subcooled to room temperature, electric heaters are employed to raise the pressure in the reactor vessel to an arbitrary value, say, 40 psig. The use of auxiliary heating is not necessary; it merely avoids using the reactor in a non-boiling manner as a water heater. The reactor is then made critical and is immediately brought to a power level of approximately 1000 kW. This is high enough to ensure that boiling takes place in the channels of the core. The energy produced heats the water moderator, while the steam bubbles in the core are condensed, probably in the cooling channels. In the meanwhile, the pressure in the reactor vessel rises steadily, but the power level remains constant and smooth. As the temperature and pressure rise, it is necessary slowly to withdraw the control rods, in order to add the reactivity lost because of the increased temperature. When the reactor pressure approaches the operating point, the control rods are further withdrawn, to cause the addition of the operating amount of reactivity, which then is subtracted by the formation of steam voids. The power rises accordingly but is smooth all the while. When the operating power level and pressure are reached, the steam delivery valve is opened and the machine is in normal operating condition.

No attempt has been made to deliver the feed-water at any particular temperature to the reactor. Lowering the temperature of the feed-water, of course, raises the reactor power. Turning the feed-water pump on and off brings a corresponding increase and decrease in reactor power, but the reactor accommodates itself to these changes in a completely stable manner. Stopping the feed-water flow, while keeping the reactor at power, lowers the level of water in the reactor vessel. Boiling off most of the upper reflector, keeping the control rods in a fixed position, reduces the power to a very low value.

With regard to the probable limit to the amount of steam, and hence the power, which could be produced by a boiling reactor, there appeared to be some differences in opinion between Russian and American thinking. Apparently, the Russians placed this limit at 60 tons of steam, whereas the Americans believed that up to one million kilowatts of heat could be produced, since the reactor pressure vessel could, with present technology, be increased to 4 metres in diameter, as compared with its present 2 metres. In addition, two other techniques could be used to increase the power output of a boiling reactor, i.e., forced circulation of the water and the use of a " dual cycle," in which part of the reactor water is diverted to another steam-producing system.

A similar type of boiling-water reactor power plant is also under development by the Argonne National Laboratory, but will have a projected heat output of 20,000 kW, a gross electric output of 4800 kW, and an operating temperature and pressure of 488° F and 600 psig respectively.

The First Atomic Power Station in the U.S.S.R.

The construction of the first industrial atomic power station in the U.S.S.R., with an output of 5000 kW, was completed in 1954, and by June of the same year this power station was actually generating electricity from the energy of fission of uranium nuclei. At present, it constitutes a real basis for the development of nuclear power in Russia.

In this station, a pressurized water-cooled thermal uranium-graphite reactor, with a rated heat-generating capacity of 30,000 kW, is used. The average neutron flux is 5×10^{13} neutrons/cm^2 per sec. The atomic fuel is enriched uranium containing 5% U^{235}, the total charge being 550 kg. The heat-transfer system consists of two circuits :—In the first circuit, the water, which circulates through the reactor, is under a pressure of 100 atm and gives up its heat through a system of heat exchangers to the water in the second circuit, which, converted into steam, drives a 5000-kW turbo-generator (Fig. 5).

The use of a two-circuit system of heat transfer eliminates the possibility of radioactive contamination of the turbine and its connections. As a result, care of the turbine and all its auxiliary equipment is exactly the same as in conventional heating and power plants, protection against radioactive radiations being unnecessary.

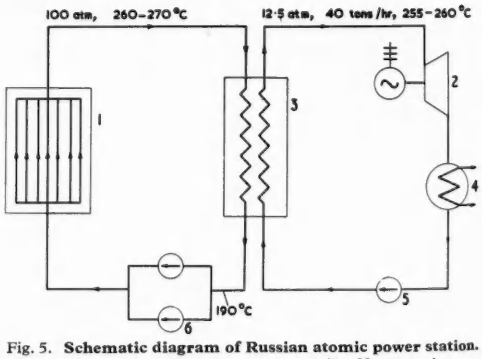

Fig. 5. **Schematic diagram of Russian atomic power station.** (1) Reactor. (2) Turbo-generator. (3) Heat exchanger. (4) Condenser. (5) Heat pump. (6) Circulating pumps.

The choice of water as the coolant for the reactor simplified a large number of engineering problems, though its presence in the reactor obliged paying special attention to chain-reaction control, inasmuch as water is the best moderator and a fairly strong absorber of neutrons, the moderating length in water being 5·7 and the diffusion length 2·8 cm, as compared with 19 and 50 cm respectively for graphite. For this reason the chain reaction of uranium fission is very sensitive to the water content in the reactor, while the water content itself inevitably varies with temperature, owing to change in density, which is specially marked at high temperatures.

There is a certain ratio between the quantities of uranium, graphite, and water at which the reactor is least sensitive to changes in water content. However,

selection of the ratio would lead to a considerable increase in the quantity of structural steel inside the reactor. For this reason the quantity of water used is less than that corresponding to the least sensitivity.

In this reactor the burn-out of U^{235} is 15%. Owing to the low resonance capture, the production of plutonium from U^{238} is low and amounts to only 0·32. However, it was expected that, by using zirconium alloys to decrease the absorption of neutrons by structural materials, this conversion ratio could be raised to 0·5 with larger versions of this type of reactor.

The chain reaction in the reactor is characterized by a rather high specific uranium-heat removal, the heat flow from the surface of the uranium being about $1{\cdot}5 \times 10^6$ kcal/m² per hour. The reactor works almost exclusively by burning U^{235}, the degree of enrichment decreasing during operation from 5 to 4·2%.

Apart from uranium enriched in U^{235}, which is the active substance, the most important element in the reactor is graphite, used as a moderator. In so far as graphite is concerned, it was established that it expands under the action of neutron irradiation, the relative change in dimensions depending on the integral dose of fast neutron irradiation. The high temperature of the graphite counteracts this phenomenon. It should be noted that this increase in dimensions is very anisotropic, owing to the peculiarities of its crystal structure and texture. Another phenomenon in connection with graphite was a decrease in its heat conductivity, this decrease also depending on the integral irradiation dose and temperature. Wherever graphite is subjected to the action of fast neutrons, i.e., in the immediate vicinity of the uranium rods, its heat conductivity may fall to a value several times smaller than its usual value. This had to be taken into account in the heat-transfer calculations of the reactor.

With regard to uranium, as a structural element it is in many respects even more troublesome than graphite, and investigations have shown that repeated heating from 20 to 500° C, followed by cooling, causes substantial changes in the dimensions of the uranium rods, which are similarly affected by neutron irradiation and by fission fragments.

For the tubes through which the high-pressure cooling water had to circulate it was essential to find a strong and non-corrosive material, which, in addition, had to be stable under neutron bombardment. These requirements were satisfactorily met by stainless steel, the ultimate strength and hardness of which have been found to improve in a neutron field. Elongation decreases considerably, but remains within tolerable limits. Furthermore, since steel is a strong absorber of neutrons, all the tubes inside the reactor had to be thin-walled, incidentally leading to lower thermal stresses.

The principal features of the reactor design were determined by the properties of the materials chosen. A general idea of the design is given in Fig. 6. The reactor is encased in a hermetic cylindrical steel jacket mounted on a concrete foundation. The jacket is filled with graphite brickwork, with proper clearance. To avoid burn-out of the graphite the jacket is filled with helium (or nitrogen). A total of 128 fuel channels pierces the central part of the graphite brickwork. Each fuel channel is a long graphite cylinder containing thin-walled steel tubes carrying the primary circuit water. The water passes through the upper head of the channel connected with the inlet and outlet headers, then runs down through the tubes and returns up, flowing over the surface of the uranium fuel elements, which form a cylindrical active zone in the reactor, enclosed by a graphite reflector. In Fig. 6, the active zone, 150 cm in diameter by 170 cm in height, is indicated by a dotted line.

The flow and temperature of the water are recorded for each channel. The indicating instruments are located on the central panel and are connected with the safety rods which stop the chain reaction when the water flow transcends the prescribed limits or when the temperature rises above the permissible level. It is very important to control the outlet temperature of the water, since this reflects the conditions in the channel. In practice, this is effected by means of a scanning light signal indicating the channels where the temperature of the water is above the prescribed limit. There is, in addition, a separate plug panel for measuring the absolute temperature of the water in any desired channel. Temperature measurement is supplemented by water-flow measurement, effected by flowmeters mounted on a separate board. A decrease in the flow of water in a channel leads to a rise in the outlet temperature. An increase in the water flow in a channel indicates a rupture in tubes of the channel or its connections.

All these deviations are dangerous and lead to a shut-down of the reactor (termination of the chain reaction) by means of the safety rods.

To prevent rapid filling of the reactor with water, in case of a rupture of channel tubes, which would lead to a rapid rise in reactivity, each channel is equipped with a cut-off device and a non-return valve to interrupt the flow of water from the header. A small water flow remains, to remove the residual heat produced by radioactive decay of the fission products. The radioactivity of the water and gas in the reactor is constantly measured, so that any rupture in the fuel elements would be indicated by a rise in activity.

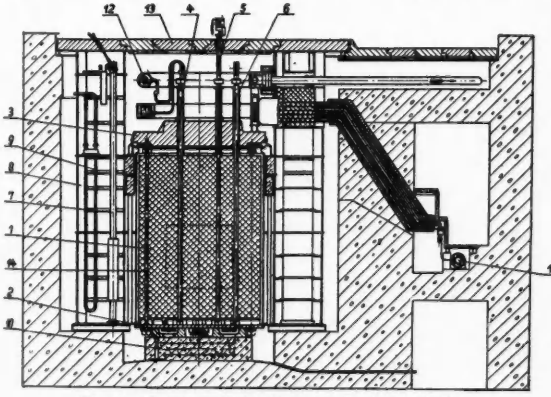

Fig. 6. **Reactor of Russian atomic power station.**
(1) Graphite brickwork. (2) Lower plate. (3) Upper plate. (4) Fuel channel. (5) Safety-rod channel. (6) Automatic control rod. (7) Ionization chamber. (8) Side shielding (water). (9) and (10) Coolers. (11) Distribution (inlet) header. (12) Outlet header. (13) Top shielding (cast iron). (14) Cooled reflector stand.

To compensate for the excessive activity of the reactor, 18 boron carbide rods are installed in the reactor, 6 near its centre and 12 at the extremities of the active zone. These rods can move in special water-cooled channels with a separate cooling system. There is also a separate cooling system for the graphite reflector. By means of wire ropes and servomotors these rods are moved vertically and their position is registered at the central panel on a special board. With these rods it is possible to regulate the outlet temperature of the water in the fuel channels.

The total submerged length of all the shim rods used for making occasional coarse adjustments of reactivity indicates the total excess of its reactivity and consequently the total above-critical quantity of atomic fuel. Therefore, the fuel quantity may be expressed in linear centimetres. A special graduated scale indicates the value of each centimetre of rod with regard to its influence on the reactor reactivity. In addition to

the shim rods, there are four automatic regulating rods for fine adjustment, located in the reflector. If the chain reaction increases these rods go down, and if it falls off they rise. One pair of rods works at a time, while the other pair is in reserve.

These regulators maintain the chain reaction at prescribed level to within 3% accuracy. Finally, there are two safety rods with servomotors installed directly over the reactor's upper shield, to ensure prompt action. In case of an emergency these rods fall freely into the active zone of the reactor and thereby stop the chain reaction. In all, there are 12 different emergency signals.

The reactor includes facilities for physical investigations and tests of materials.

Biological shielding is effected by a side water shield 100 cm thick and a concrete wall 300 cm thick. In the upper part of the reactor, shielding is ensured by intensification of the graphite reflector, by the upper steel cover of the apparatus, and by a cast-iron plate. The shielding attenuates the fast neutrons which have escaped from the reflector, and the gamma radiation from the radioactive fragments and from the thermal neutron capture in the iron of the construction.

Considerably greater quantities of uranium have been loaded into the reactor of the atomic power station than were necessary to attain the critical mass which makes the chain reaction possible. It was established that this mass is reached with only 60 uranium rods in operation. The complete loading consists of 128 uranium rods in operation.

When the reactor reaches a sufficient power level, its reactivity will drop considerably, owing to the heating of the water. Moreover, xenon, with its tremendous resonance absorption, is formed, also leading to a drop in its reactivity (xenon "poisoning"). Lastly, its reactivity drops slowly during operation due to the burning out of U^{235} and the formation of the fission products absorbing the neutrons (slag). All these effects make it imperative that the quantity of uranium should considerably exceed the critical mass of the cold reactor.

All rooms in the station are well ventilated, and air normally escapes through a high chimney. When the station is working normally, a slight source of radioactivity is that acquired by the argon in the air near the reactor. Radioactive water, when the water is let out of the primary circuit, is discharged to storage tanks, where its activity is reduced to the safety level by dilution and decay.

Since the station was first started up, it has been tested under various operational conditions and has produced about 15 million kWh of electrical energy.

During operation, there has not been a single case of failure of a fuel element, indicating that heat transfer from the uranium elements to the water proceeds without disturbances. The durability of the fuel elements has ensured reliable operation of the station as a whole. It should, however, be mentioned in this connection that, despite questioning by various delegates at the Conference, details of the design and construction of the fuel elements were not clarified, nor was it confirmed whether or not a uranium-molybdenum alloy was used.

The automatic set-up of steam generator control is so stable in operation that the steam parameters are quite constant. Furthermore, the automatic control system and the breakdown protection system of the reactor functioned without mishap.

Fuel channels were found to be easily removable and water flow through the channels was stable during operation. The temperature of the graphite proved to be above the rated temperature, and at the hottest points reached 650 to 700° F.

Start-up of the reactor from zero to rated power takes approximately half an hour and is the most important operation, especially when the reactivity of the reactor is not precisely known. Unloading of the uranium fuel elements from the reactor is carried out in sections, with a view to economizing atomic fuel. The reactor is simultaneously loaded with fresh elements, and the less burnt-up periphery elements are moved to the centre of the apparatus, resulting in an extension of the operational period of the fuel elements and an increase in the burning depth of U^{235} to 20%. The elements are replaced once in two months, an operation requiring from two to three days.

The main technological equipment of the station (pumps, steam generators, volume compensators, etc.) functioned without failure. High purity of the water in the primary circuit was found to be necessary for successful operation of the reactor.

It was found that there was no formation of detonating mixtures in the primary water circuit, so that recombining apparatus could be dispensed with.

Operational experience of the station has shown that the various warning systems of elevated gamma and gas activity function satisfactorily.

Power Reactors under Development or Construction

As already stated, there are, in addition to the power reactors in actual operation already described, a number under development or construction. Some of these are expected to be put into service in the near future, whilst others still require considerable development work and are not likely to be in operation before 1960. In this connection, it has been announced by the Russians that they intend to put into operation a nuclear power station with an electrical output of 100,000 kW within a year. However, when pressed for details, there was a marked reluctance on their part to disclose any information, even the type.

Descriptions of some of the more interesting of these power reactors under development or construction are appended.

The Shippingport Pressurized Water Reactor Power Plant :—

Sponsored by the U.S. Atomic Energy Commission to further the peaceful uses of atomic energy in the field of electric power generation, the design, construction, and operation of the full-scale nuclear-power plant to be constructed at Shippingport, near Pittsburgh, Pa., will provide considerable knowledge in the fields of reactor physics, fuel-element, and core technology, and component and system design. Furthermore, the plant organization will provide training for personnel for future plants.

The basic schematic diagram of the reactor and steam plant is shown in Fig. 7. The nuclear reactor is the heat source and produces a minimum full-power rating of 790×10^6 BTU/hr. This heat is produced in a nuclear core, which is a right circular cylinder consisting of assemblies of enriched uranium in clad plates and natural uranium in tubes. These assemblies are supported in a bottom plate and top grid, which, in turn, are supported from a ledge of the reactor pressure vessel. This reactor vessel is a cylinder with a hemispherical bottom and a removable hemispherical top closure. Coolant enters through four nozzles at the bottom of the reactor vessel and leaves through four nozzles at the top.

The reactor plant consists of a single reactor heat source with four main coolant loops. Three of these loops are required for producing the 60,000-kW minimum design power. Each loop consists of a single-stage centrifugal canned-motor pump, a heat-exchanger section of a steam generator, gate-type isolation valves, and the necessary interconnecting piping.

High-purity water, at a pressure of 2000 psi, serves as both coolant and moderator. The flow through the nuclear core is 45,000 gpm for three loops. At full power the inlet water temperature to the reactor is 508° F and the outlet temperature 542° F. The total pressure drop around the main coolant loop is 105 psi, and this drop is roughly divided equally between core, steam generators, and piping.

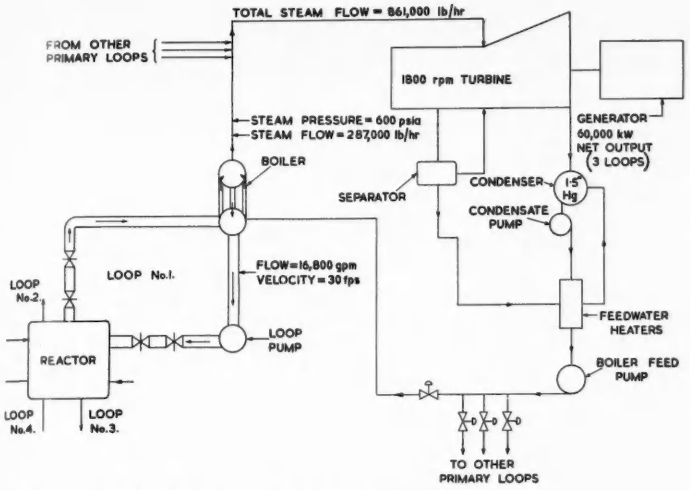

Fig. 7. **Schematic diagram of the Shippingport reactor and steam plant.**

In general, the cost of equipment can be minimized by making the individual units larger and thus reducing the number required. There is, however, a competing factor in the increased mechanical complexity and fabrication difficulty associated with increased component size. The four loops selected give units which are about as large as is practical with present technology. The use of four loops gives the plant considerable operating flexibility, because any one or even two loops can be shut down and even repaired without shutting down the remaining loops.

One advantage of the design chosen is flexibility. This means that at any time, even after operation has begun, the core can be rearranged and the number of control rods changed to take advantage of knowledge gained in the critical experiment programme. It also may be desirable to rearrange the fuel sub-assemblies at various times during the life of the core to compensate for reactivity changes or to equalize fuel burn-up.

Great improvements probably can be made in the nuclear cores for this plant. To take advantage of this, the reactor vessel and the primary coolant system have been arranged to accommodate cores considerably larger than the first to be installed, and with flow and pressure-drop requirements covering a wide range. It is expected that the first core will produce substantially more power than the 60,000 kW minimum plant rating. It is also expected that sufficient information will be obtained from the operation and test of the first core, so that subsequent cores may produce sufficient heat energy to be compatible with the 100,000-kW rating of the turbo-generator.

Owing to lack of basic knowledge on pressurized water reactor plants, a considerable number of rather costly safety features, such as the plant container, have been included. The experience gained in operation of this plant will enable such features to be evaluated and therefore possibly removed from future plants.

To restrict the spread of radioactivity in the event of a dual casualty (i.e., rupture of the primary coolant system and subsequent melting of the nuclear core with attendant release of fission products) the nuclear part of the plant is completely inside a steel container. This container is designed to contain the pressure created by a rupture of the primary coolant system of the most adverse size, including the effect of the stored energy in the water and the metal, as well as any conceivable energy release due to a zirconium-water reaction.

The plant container is divided into four units connected by large tubular ducts. The reactor vessel is located in a spherical section, and two of the main coolant loops are in each of the adjacent cylindrical sections. The fourth cylindrical section is connected into the other three and contains the pressurizing and other auxiliary systems.

The reactor pressure vessel is supported at a point just above the outlet nozzle level by the primary shield tank, to permit radial thermal expansion of the

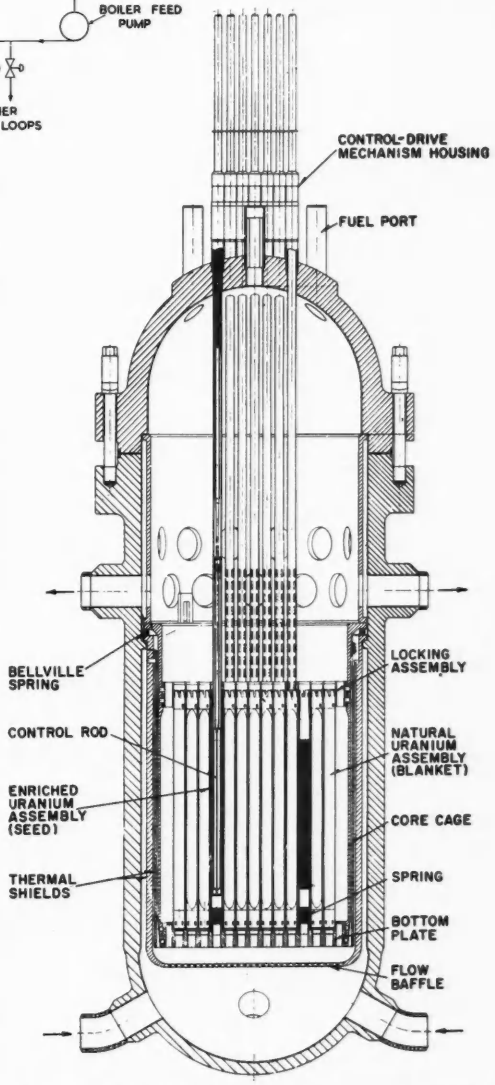

Fig. 8. **Longitudinal section of Shippingport reactor vessel.**

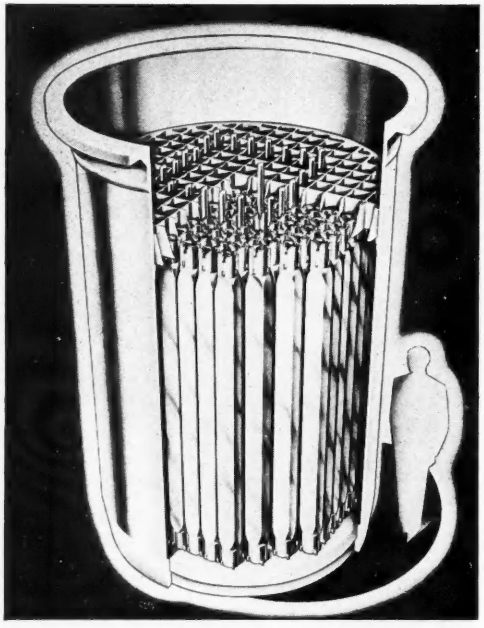

Fig. 9. **Cut-away view of core of pressurized water reactor.**

four main coolant loops. The steam generators are supported by conventional constant-load spring hangers.

The reactor vessel, shown in Fig. 8, has an overall height of 33 ft., with a cylindrical section with an internal diameter of about 9 ft and a nominal wall thickness of 8½ in. The vessel has a bottom hemispherical head and a standard bolted and flanged top closure modified to use a gasket or a seal weld for the final sealing. The total estimated dry weight of the reactor vessel is 250 tons.

The core assemblies are supported in a stainless-steel cage, consisting of a barrel, a bottom plate, and a support grid. The cage is nearly 8 ft in outside diameter and slightly over 13 ft high. It is supported in the reactor vessel by a flange just below the outlet ends of the assemblies. The reactor vessel is surrounded by an annular neutron shield tank, providing a water layer 3 ft in thickness.

The pressurizing tank is 18 ft high and 5 ft in inside diameter, with a total volume of 300 cu ft, of which about 150 cu ft is the steam-dome volume with maximum water level. Normal surges will be as great as ± 10 cu ft under design plant-load fluctuations. Under these design conditions primary-system pressures will be held within limits of 1850 to 2185 psia. A 6-in. surge line in the bottom head connects this tank with the primary coolant system.

The heater section contains 200 heater wells, into which are inserted 500 kW of replaceable electric heaters. These are arranged electrically into three groups for operational convenience and are controlled to maintain a saturation temperature of 636°F (corresponding to a pressure of 2000 psia) and to form a steam bubble in the top of the tank. A spray nozzle at the top injects colder water (500°F) into the steam during positive surges to help limit maximum pressures. A low-level alarm warns the operator to add water to the system before the level drops to a point where negative surges could uncover heater wells.

The active portion of the nuclear core is in the form of a right circular cylinder 6 ft in mean diameter and 6 ft high. To minimize the amount of enriched U^{235} used, the core consists of some highly enriched seed and some natural blanket assemblies of fertile material, i.e., one capable of being transformed into a fissionable substance by capture of a neutron. The highly enriched, or seed, assemblies are located in a square annular region about 6 in. thick. The area inside and outside the annulus is filled with natural uranium oxide sub-assemblies. A cut-away view of the core is shown in Fig. 9. Each seed sub-assembly consists of several plates welded together to form a box. Four of these box-type units are welded together, with separation maintained by spacers, to form a central cruciform-shaped area. In each of these areas is located a cruciform-shaped hafnium control rod.

The uranium oxide, or blanket assemblies, use a rod as the basic element. These rods are Zircaloy-2 tubing with a 0·413-in. outside diameter and a 0·028-in. wall. The tubes are filled with UO_2 pellets and have Zircaloy-2 end-plugs welded to each end to form fuel rods. These rods are assembled into bundles of 100 rods each; the assembly is made by mechanically fastening together a stack of seven bundles, each about 10 in. long, for a total of about 6 ft. The individual rods are welded to plates at each end. Holes are drilled in the plates between the rods to permit the flow of coolant water.

The seed assemblies contain a total of 52 kg of enriched U^{235}, and the blanket contains twelve tons of UO_2. At the start of reactor life, approximately 60% of the power will be produced in blanket assemblies and 40% in the seed assemblies. The power distribution is a function of reactor life, inasmuch as the reactivity of both the seed and blanket vary with reactor life. The percentage of power produced in the blanket is expected to increase with time. Obviously, power distribution is also a function of the reactor temperature and the position of the reactor control rods.

In this reactor most of the power comes from the fissioning of U^{235}. However, approximately 8% is derived from the fast fissioning of U^{238}, and a substantial fraction from the fissioning of plutonium. This latter effect increases with the lifetime of the reactor and is expected to reach a substantial fraction after 3000 MW-days/ton average burn-up in the blanket assemblies. At the start of life, approximately 0·8 atoms of plutonium are formed for each atom of U^{235} fissioned.

The fuel-handling building (Fig. 10), which is the largest building on the site, is 44 ft wide, 182 ft long, and has an overall height of 60 ft. The 100-ton crane at the top of the illustration is provided for removing the reactor-vessel closure and the core as a complete unit, if desired. Equipment is also provided for removing any

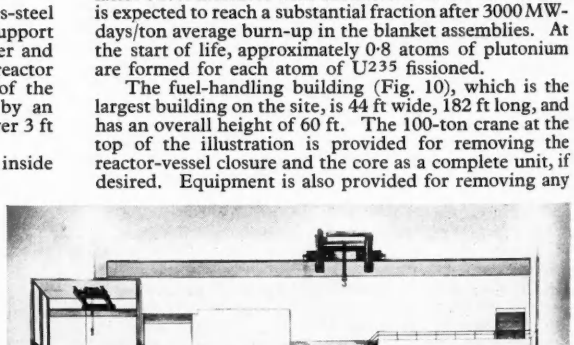

Fig. 10. **Fuel-handling facilities at Shippingport.**

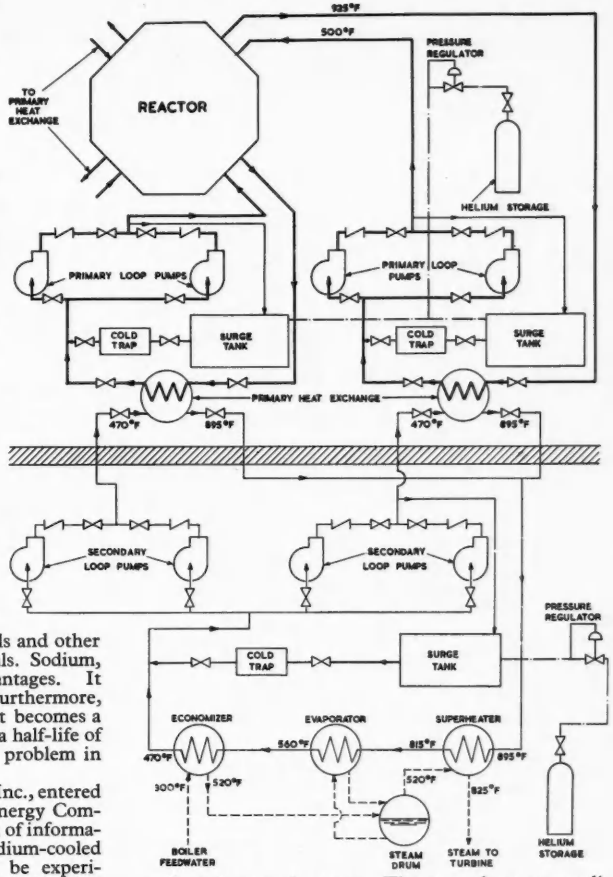

Fig. 11. **Schematic diagram of sodium graphite reactor power plant.**

Thick full line, primary sodium loop. Thin full line, secondary sodium loop. Dotted line, steam and feed-water system. Chain-dotted line, helium system.

fuel assembly or group of assemblies, or for rearranging them either through the fuel ports in the closure head or with the head removed. The fuel assemblies will be removed from the reactor vessel under water and will be transferred to the appropriate section of the canal for storage, further disassembly, repair, or examination.

75,000 kW Sodium Graphite Reactor in the U.S.A. :—

The use of a liquid metal such as sodium as a heat-transfer fluid has many advantages. While solid at room temperature, it melts at 208°F and is therefore easy to keep liquid in a power-plant system. Sodium boils at 1620°F and thus permits adequately high coolant temperatures with the system at atmospheric pressure. Because liquid metals, sodium in particular, have extremely high thermal conductivity, they are excellent heat-transfer media. A further advantage of sodium is the general absence of chemical corrosion in metal systems. As a result, a wide variety of steels and other alloys may be utilized as construction materials. Sodium, however, is not without certain disadvantages. It reacts chemically with oxygen and water. Furthermore, when exposed to neutrons, as in a reactor, it becomes a strong radioactive gamma-ray emitter with a half-life of about 15 hours, and this creates a serious problem in nuclear power-plant applications.

In mid-1954, North American Aviation, Inc., entered into a programme with the U.S. Atomic Energy Commission, aimed at expanding the known area of information on the sodium graphite reactor. The sodium-cooled graphite-moderated reactor approach will be experimentally demonstrated through the construction and operation of a Sodium Reactor Experiment. This is a 20,000 thermal kilowatt pilot reactor, incorporating the major design features of the full-scale sodium graphite reactor. An experimental engineering programme, with the aim of attaining the potential performance of this high-temperature, low-pressure reactor system, is an important part of the joint project. The Sodium Reactor Experiment will be fully operative early in 1956. Experience in construction, test, and initial operation will be available for incorporation into the full-scale sodium graphite reactor power plant, which is at present conceived to produce 75,000 kW of net electrical power.

The proposed plant consists of a reactor core cooled by a primary sodium loop, intermediate heat exchangers, a secondary sodium coolant loop, steam generators, turbo-generators, condensers, and electrical and auxiliary equipment. A schematic flow diagram of the plant is presented in Fig. 11.

There are two reactor core designs for this plant. One is for use with slightly enriched (1·8%) uranium fuel and the second for use with thorium-base fuel. The two reactors are identical in all design aspects. They differ only in the type of fuel element employed and certain physical dimensions.

The reactor core is contained in a large-diameter steel tank, located below ground and cooled by liquid sodium. The sodium coolant is separated into four independent loops and flows from the reactor by means of radial discharge pipes to four intermediate sodium-to-sodium heat exchangers. The secondary, non-radioactive sodium from each intermediate heat exchanger is pumped above ground to the steam generators, which are sufficiently removed from the main building and the electrical generating equipment to eliminate damage to these units in case of a tube failure which might result in a sodium-water reaction.

The present temperature limitations in these reactor cores are a result of the limited experience with zirconium and steels in sodium, and also with fuel elements, at high temperature. The physical properties of zirconium are known to be affected by trace impurities such as oxygen, nitrogen, and hydrogen. The extent to which such impurities can be controlled in large sodium systems has not as yet been determined. Furthermore, the mechanical behaviour of zirconium under practical high-temperature conditions for prolonged periods is uncertain. For this reason, the maximum sodium-zirconium temperature has been held to a conservative 950° F.

The use of uranium-metal fuel elements at high temperatures is complicated by the alpha-beta phase transition which occurs at about 1220° F and its accompanying volume change. While it may be possible to operate with a mixed-phase situation at high temperatures, insufficient experience exists. For this reason, the maximum uranium-metal temperature at the centre of the fuel elements has been limited to 1200° F. In this regard, thorium offers interesting possibilities, since a maximum metal temperature of 2000° F may possibly

be utilized, owing to the absence of phase transitions. Here again, more experience under practical operating conditions is needed.

The reactor core consists of an array of closely packed, canned, hexagonal graphite cells contained within a large steel tank (see Fig. 12.) The tank is surrounded by a thermal shield and a layer of thermal insulation. Since the reactor is located entirely below ground level, the concrete foundation provides adequate biological shielding. The top shield is composed of several feet of heavy concrete and could be removed, should major repairs to the core be required. The reactor has been designed to produce a thermal power of 250 MW. The sodium inlet temperature to the reactor has been selected as 500° F, so that the desired steam pressure may be produced. The number of fuel channels and the velocity of coolant through the core were chosen so that a mean bulk outlet temperature of at least 925° F would result.

The fuel elements consist of clusters of 19 rods. Each rod is made up of ten slightly enriched uranium fuel slugs. The rods are contained in a stainless-steel jacket, which is sealed at the top and bottom with a plug and, except for a helium-filled expansion space, is filled with a bonding material (either sodium or NaK). The rods are spaced from each other by helically wrapped steel wires.

The rods are joined to a common hanger rod, by which they are suspended in the coolant channels located in the moderator elements. The hanger rod is supported from the top shield by a shielding plug. On each assembly there is an orifice plate to throttle the flow of coolant to each fuel cluster, in such a way as to obtain maximum bulk coolant outlet temperature.

The moderator elements are graphite columns contained within sealed zirconium cans. There are small gaps between the zirconium and graphite to allow for thermal expansion and clearance for assembly. A small clearance is also provided between adjacent can walls to permit sodium coolant to flow between these elements. The canned reflector elements are similar, except that they do not contain fuel channels or coolant tubes. There are 233 moderator elements, forming an

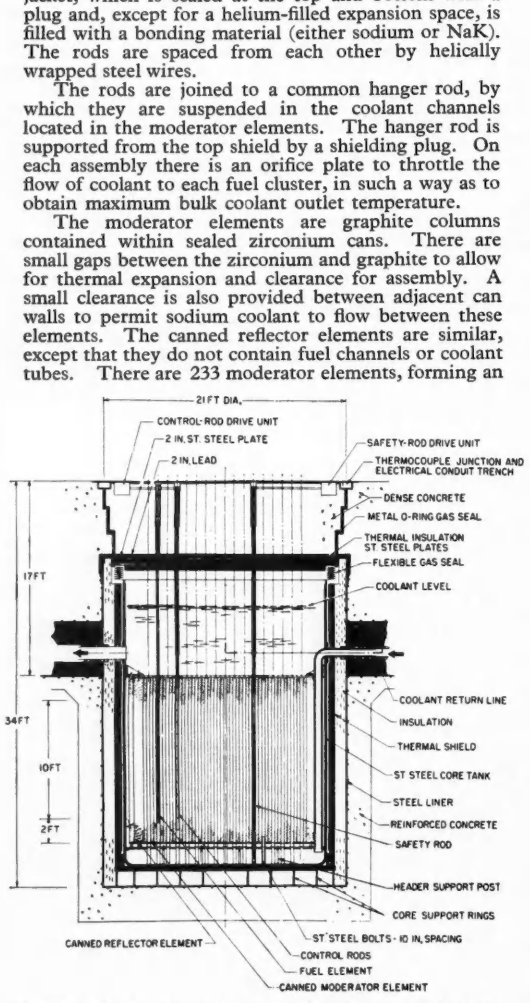

Fig. 12. **Section through reactor of sodium graphite plant.**

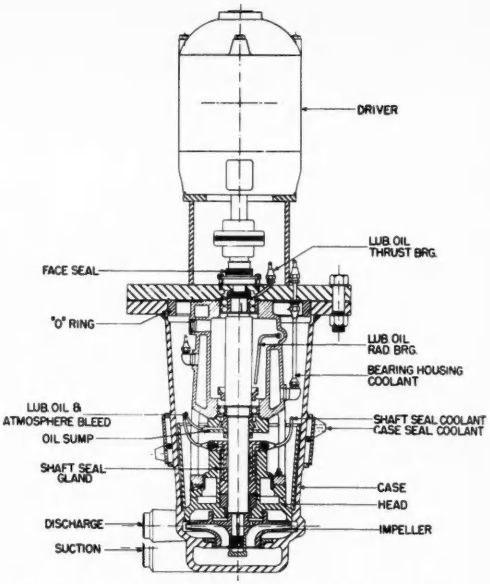

Fig. 13. **Cross-section of "frozen-seal" sodium pump.**

active core 13·3 ft in diameter by 10 ft high. A 2-ft reflector surrounds the core both in the radial and axial directions, resulting in overall dimensions of 17·3 ft in diameter by 14 ft high.

The primary sodium coolant removes heat from the fuel elements, the moderator and reflector elements, and the thermal shield. This useful heat represents more than 98% of the total energy produced. The heat generated in the neutron shield and losses through the thermal insulation are removed by a separate low-temperature cooling system, using an organic liquid such as toluene, which is chemically non-reactive with sodium. The sodium cooling system is divided into primary and secondary sections, so that the radioactive primary coolant is contained in a small volume and is separated physically from the steam generator units. The coolant in each loop leaves the core at a level just above the top of the moderator and reflector units and thence flows to the inlet of specially developed "frozen-seal" sodium pumps (Fig. 13).

Because of the radioactivity induced in the sodium, that portion of the primary sodium system not inside the reactor must be surrounded by a gamma shield. The sodium-to-sodium heat exchangers, primary system piping, and pumps associated with each loop are located in four vaults adjacent to the reactor and below ground level.

The secondary non-radioactive sodium system receives its heat from the primary system with approximately a 30° F loss in temperature, and gives up its heat to steam in the superheaters, evaporators, and economizers.

A total of 18 control and safety elements is provided. Each operates within a stainless-steel thimble, which extends through the core in regular coolant channels.

The thermal shield is made of mild-steel interlocking slabs, approximately 6 in. in thickness, located just outside the core tank. Thermal insulation is placed between the thermal shield and the biological shield or foundation walls, to reduce the heat losses. Most of the heat generated within the thermal shield is radiated or conducted back into the core tank and removed by the sodium coolant. The temperature of the thermal shield will vary from around 500° F below the reactor to

approximately 1200° F in the central portion of the upper thermal shield. The foundation, made of ordinary reinforced concrete, is lined with a mild-steel plate. An organic liquid is circulated through cooling tubes welded to this plate.

The sodium service system consists of equipment required for melting, filtering, and transferring sodium to the primary and secondary coolant systems. An inert gas, either helium or nitrogen, is used wherever an inert atmosphere is necessary to prevent oxidation of either graphite or sodium.

The fuel-handling system replaces the irradiated fuel elements with new fuel elements while the reactor is shut down. In addition, this system is designed to store, inspect, clean, and transport new and spent fuel elements. While the reactor is shut down, the fuel-transfer cask is used to transfer new fuel elements to the reactor and to remove spent fuel elements from the reactor and then transfer them to a cleaning cell. After reactor operation is resumed, the cask is used to transfer the irradiated elements from the cleaning cells to the storage cells. The design permits making and breaking gas-tight connections between the cask and the reactor loading face, the new fuel storage cell, or the cleaning cells.

In the design described, the mean temperature of the primary sodium has been limited to 925° F, and the steam conditions chosen are 800 psig at 825° F, with a feed-water temperature of 300° F. These steam conditions appear to represent the best compromise between a low cycle heat rate, adequate temperature drives in the sodium/water heat exchangers, and permissible moisture in the turbine exhaust.

The present development programme is expected to raise the limitation on maximum sodium temperature. Advances in this direction will permit a further increase in thermal power, and will also result in improved steam conditions. With a Th-U^{235} fuelled reactor, the thorium-base fuel element is particularly suitable for use with higher sodium temperatures, since very high centre temperatures with the metal can be sustained. Even now, if there is no objection to sacrificing nuclear performance to thermal efficiency, stainless steel could be used instead of zirconium, and a sodium outlet temperature of 1200° F could be obtained from a thorium-fuelled reactor. With the eventual availability of higher sodium temperatures, the use of a reheat-regenerative steam cycle or a supercritical-pressure cycle will become desirable.

With the thorium-uranium reactor version, the conversion ratio is given as 0·81. However, there is every reason to believe that a slightly larger reactor with improved core design and utilizing an effective blanket arrangement will yield conversion ratios of about unity. Thus, after the initial fuel loading, the only feed material to the plant would be thorium metal.

The Calder Hall Graphite-Moderated, Gas-Cooled Nuclear Power Plant :—

While the Windscale piles, in which all the heat is wasted, were being built in Great Britain, study of the graphite-moderated, pressurized, gas-cooled pile, from which power could be produced, was continued, and in 1953 it was decided to proceed with the construction of a graphite-moderated, gas-cooled nuclear plant at Calder Hall, in Cumberland. This plant, a model of which (Fig. 14) was shown at the Exhibition held in conjunction with the Geneva Conference, is expected to be in operation in 1956.

The mass of graphite moderator, weighing over 1000 tons, is contained in a cylindrically shaped pressure vessel. The machined graphite blocks have vertical uranium charge and control-rod channels, the adoption of vertical channels simplifying the graphite structure and making the design of the coolant circuit more convenient. The weight of the graphite is taken on a diagrid structure, which consists of an I-section ring girder spanned with steel girders, forming a rectangular lattice. Across the members of the diagrid lattice are bolted steel base-plates, 4 in. thick, with holes in them to coincide with the channels in the graphite. These base-plates support the graphite through a number of races, which allow for differential thermal expansion of the diagrid and graphite. The weight of graphite and diagrid is taken by brackets directly through the walls of the pressure vessel onto ten inverted A-frames which rest on the thermal shield. These frames are loosely bolted to the brackets on the pressure vessel and to the thermal shield, the three contact surfaces of each frame being radiused. In this manner, allowance is made for radial thermal expansion of the pressure vessel and diagrid, when the frames roll slightly out of the vertical, while the bolts ensure that the rolling surfaces do not slip.

The pressure vessel is of 2 in. welded steel plate, about 40 ft in diameter and approximately 60 ft high. Fabrication was carried out on site. Extensive site-welding facilities were set up, and the vessel was built up into five main sections, i.e., the bottom dome, the two parallel centre sections, the diagrid, and finally the top

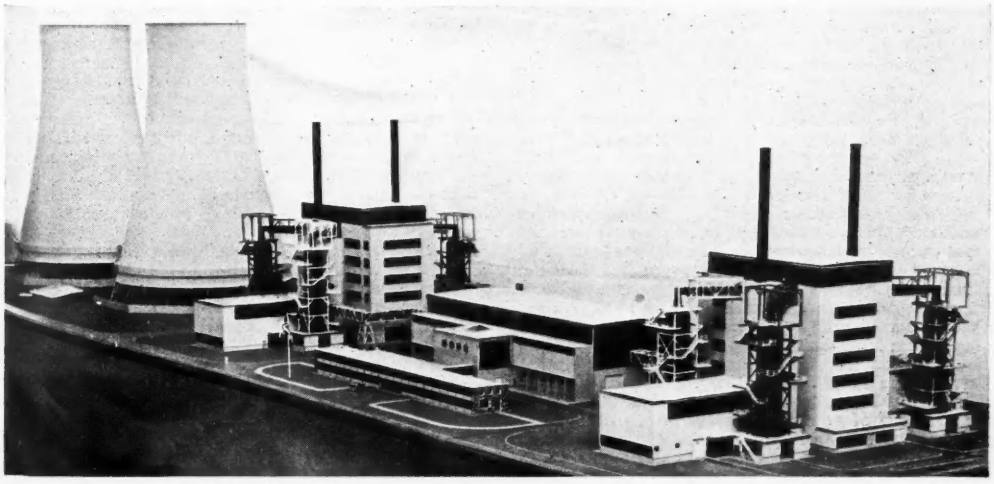

Fig. 14. Model of Calder Hall graphite-moderated gas-cooled nuclear power plant.

dome. Each butt weld was radiographed and all important fillet welds were examined by crack-detection techniques. The task of stress-relieving the completed vessel was achieved by radiant heating which required a peak electrical load of about 1½ MW. The vessel temperature was brought up to over 550° C and held there for 8 hours before being allowed to cool slowly and evenly. The vessel was then subjected to pressure tests. The use of hydraulic testing techniques would have overloaded the structure, and for this reason a pneumatic test was carried out. A constant check on the behaviour of the vessel by means of strain and other gauges was maintained throughout the test.

The final test was under vacuum at 0·1 atm and was done by means of the large rotary vacuum pump which is part of the operational equipment required for exhausting the vessel when charging or changing the CO_2 coolant.

The reactor charge and discharge arrangements are accommodated on the pile vault roof along with the pile control and shut-off gear. Emerging from the reactor top dome are the charging tubes, which terminate at the upper surface of the pile vault roof. An overhead crane lowers the charge chute into the desired charging tube, and the charge machine supplies fuel elements from a magazine. Conversely, the discharge machine removes spent fuel elements by withdrawing them up the charge chute and placing them in a basket, where they are kept cool. The basket is lowered into a coffin at the bottom of the discharge well, the coffin lid is automatically positioned, and the coffin is withdrawn from the discharge room to be transported to the cooling-pile pond. The control rods and shut-off rods are made of stainless-steel tube lined with boron-steel fillers and are suspended through the roof of the pile.

The hot CO_2 coolant is led away from the top of the pressure vessel by circular mild-steel ducts of 4 ft 6 in. diameter to the four heat exchangers which are situated at the corners of the pile building. The cool CO_2 coolant from the base of each heat exchanger is boosted by four main blowers and returned to the inlet manifold at the base of the pressure vessel. Motorized isolating valves of the wedge gate type are included in each hot and cold duct, and flow cascades are fitted at the bends in the ducts. The problem of accommodating the large thermal expansions between the pressure vessel and the heat exchangers under various conditions of operation is solved by the use of "hinged bellows" in the ducts. The duct flexibility is obtained from the bellows, which are of welded steel plate, while the thrust due to the internal pressure of the gas is taken by the pin joint in the bellows assembly. The whole duct structure is carried on spring-type constant-load supports. The four CO_2 coolant blowers are of the single-stage centrifugal type with an overhung impeller. The overhung impeller arrangement has the advantage of requiring only one gland, but it has the additional advantage of facilitating an arrangement in which the gland and bearings can be so located that access to them can be obtained without exposure to radiation above tolerance level. The gland is of the face-seal type.

It was decided that control of the mass flow of coolant could best be carried out by controlling the speed of rotation of the blowers in preference to varying the static pressure of the coolant system as a whole. Thus, the d.c. motors, which develop some 2000 hp each, are supplied from motor generating sets in the blower house, permitting the blower speed to be varied over the range of 10 : 1. About 2% of the mass flow through each blower is taken from the downstream side of the blower, filtered, and reintroduced to the system on the upstream side of the blower, with a view to preventing the accumulation of graphite dust and iron oxide in the coolant system. A constant check is kept on the water content of the coolant, which is kept down by alumina drying units, which hold the dew point of the CO_2 below the necessary limit. Continuous monitoring of the coolant gas stream for the detection of burst fuel elements is also carried out.

Over 20 tons of CO_2 are required to complete the filling of the reactor and coolant circuits. Charging is carried out by exhausting the system and then admitting CO_2, which is generated from eight standard converters charged with blocks of solid carbon dioxide. Purging by repeated charging and discharging is necessary in the first filling.

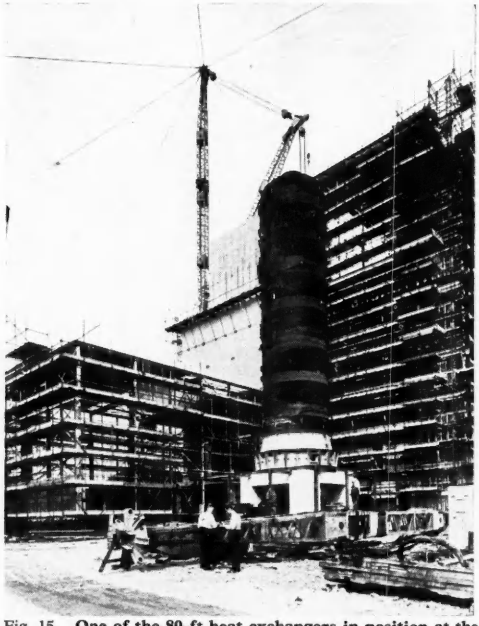

Fig. 15. **One of the 80-ft heat exchangers in position at the Calder Hall nuclear power plant.**

Each of the four heat exchangers (Fig. 15) is about 18 ft in diameter and some 70 ft high. The 30,000 sq ft of water-heating surface, comprising high-pressure and low-pressure economizer, evaporator, and superheater sections is made of mild-steel tubing. The gas surface of the tubes is extended by the use of elliptical steel-stud tube construction. Flow in the evaporator sections is by forced circulation from electrically driven pumps, which maintain a circulation rate of about four times the steam output of the section. Each evaporator has a single steam drum, 4 ft in diameter and 18 ft long, which contains conventional cyclones and scrubbers. Particular attention has been given to minimizing the possibility of steam or water leaking into the coolant circuit by keeping the number of tube joints contained within the pressure shell to a minimum. All tube joints sited within the first heat exchanger to be assembled were subjected to an abnormally high pressure test, followed by a stringent vacuum test. The ends of each tube element pass separately through a sleeve in the pressure shell, so that, if leakage should occur at a joint, steam will escape to atmosphere. As in the case of the reactor pressure vessel, the final assembly of the heat exchangers was effected on site. Each heat exchanger arrived in nine main sections consisting of the dished ends, the six circular centre sections, and the skirt. After the heat exchangers were assembled and inspected, the final welds were stress-relieved, and the heat exchangers were lifted onto their concrete plinths.

The dual-pressure steam system used obviously adds complexity in the design and operation of the station and it was adopted only after careful consideration. The steam is taken to the generator house, which is situated

between the pile buildings, where four turbo-alternator sets are installed. The turbines are two-cylinder reaction machines of established design. Each turbine is directly coupled to a 3000-rpm air-cooled alternator of standard design, having a full-load capacity of 23 MW at 11 kV.

A separate " dump " condenser is provided, in which up to the full-load steam production of the heat exchangers may be condensed without passing through the turbines. The condensate from the dump condenser is de-aerated and fed back into the heat exchangers. The dump condenser is essentially for use during start-up and shut-down of the plant but, if required, it will permit the reactors to be run at full load in the event of turbine outage. A closed-circuit cooling-water system is employed for the condensers. Cold water at about 21° C is fed from the cold pond to the suction basin, where four electrically driven pumps send the water to the condenser battery. The hot water, at a design temperature of 30° C, is fed to the sprays in two natural-draught cooling towers, whence it returns to the cold-side pond. The cooling towers are each capable of cooling 3,000,000 gallons of water per hour by 10° C.

The core of the reactor is surrounded by an octagonal-shaped concrete biological shield several feet in thickness, protected from thermal and radiation effects by a thermal shield constructed of 6-in. mild-steel plate. Induced-draught air cooling is supplied to the space between the thermal and biological shields, and the outlet air is exhausted 200 ft above ground level from the two stacks on the pile building.

The Calder Hall type of reactor is essentially a heavy, land-based plant, using low specific ratings. It does not, however, require expensive constructional materials. Whilst the cost of electricity production in such a plant is not competitive with that of conventional power stations, it will be improved considerably, once an outlet for the by-product plutonium has been found, e.g., by recycling it or by using it in advanced types of reactors such as the Dounreay reactor, a description of which will be given later.

The Hanford Graphite-Moderated Nuclear Power Plant:—

Basically similar in design to the first atomic power station in the U.S.S.R., already described, the Hanford graphite-moderated, high-pressure water-cooled plant in the U.S.A. will employ pressurized reactor cooling water contained in a forced-circulation primary loop, the heat generated in the reactor being given up in heat exchangers, in which the steam formed is passed to the turbine in a secondary loop. The Hanford plant, however, will have a reactor of 800,000 kW thermal rating, combined with a power-generation system capable of producing 223,000 kW of net electrical power.

Heat will be removed from the reactor by recirculation of 21,700,000 lb/hr of high-purity water through the process tubes to the heat exchangers. At full power the reactor outlet water temperature will be 585° F and the pressure 1860 psia. The reactor cooling water will leave the heat exchangers at 485° F and 1840 psia.

An interesting feature will be the use of electrically driven primary pumping units fitted with flywheels. If the electric power to the primary pumps is lost, the reactor will shut down. However, the flywheels will permit the pump speed to decrease gradually from their 1800 rpm normal speed to the 600 rpm secondary winding speed, at which time the emergency power source would supply the pump motors to maintain shut-down flow. These flywheels are designed to provide sufficient energy to maintain adequate reactor cooling during the shut-down transient period.

Heavy-Water Reactors :—

Heavy water comes very close to meeting technical specifications for an ideal moderator material. Of the materials commonly considered as moderators for reactors, the slowing-down power of heavy water is second only to that of light water. The combination of good moderating power and low absorption cross-section for thermal neutrons gives heavy water a moderating ratio far greater than any other material. Heavy water is the only moderator which can be seriously considered in a high-performance power reactor using natural uranium. With reasonable care in the design, to prevent excessive amounts of neutron-absorbing structural materials in the core, a large, natural-uranium power reactor should be able to operate with a conversion ratio near unity. This high conversion ratio assures maintenance of reactivity for the high fuel burn-up necessary for economic reasons.

The intermediate slowing-down power and low absorption cross-section of D_2O encourage core lattice designs in which the volume ratio of D_2O to uranium is very high. Common values of this ratio for D_2O and H_2O reactor cores are in the neighbourhood of 20 and 2, respectively. The small volume of uranium makes the core design, fuel handling, and control of the D_2O reactor much simpler than in its H_2O counterpart. The small quantity of uranium and low absorption cross-section of the moderator account for a prompt neutron lifetime more than 10 times as long in a D_2O reactor as in the H_2O type. This is a very important factor from the safety standpoint, inasmuch as short-period excursions need not be considered in D_2O reactors. Since a significant part of the capital expenditure for a nuclear power plant is usually associated with safety provisions, the relative safety of a D_2O reactor is expected to have an important bearing on the cost of electricity. Furthermore, despite the fact that the chief disadvantage of D_2O as a moderator has been its high cost, it is now clear that its cost of production can be markedly reduced by mass-production techniques.

Direct-cycle boiling-reactor power plants are particularly suitable for the use of D_2O as moderator and coolant. The only D_2O required outside the reactor is a very small amount in the form of steam and condensate. In a pressurized-water type the amount of D_2O required in external pipes, boilers, and pumps approximates that in the reactor itself. The advantages of a D_2O moderator are best realized in reactors of large physical size. To achieve criticality and to operate at high temperature with natural-uranium fuel, D_2O-moderated reactor cores must be 10 ft or more in diameter. When the reflector is taken into account, a pressure vessel with a diameter of at least 13 ft is required. For a boiling reactor generating 600 psi steam, the thickness of the pressure-vessel wall would be about 4 in. For a pressurized water reactor operating at 2000 psi, in order to generate 600 psi steam in external boilers, the wall thickness of the pressure vessel would be so great that fabrication would be extremely difficult, if not impossible.

The choice of an optimum reactor design for power production depends upon the assumptions which must be made regarding availability of slightly enriched uranium and on the amount of power desired per reactor. If only natural uranium is available, D_2O reactors are necessarily large, and H_2O reactors are excluded entirely. A D_2O natural-uranium reactor, which is large in physical size and capital investment, must produce large quantities of heat, if the unit cost of this heat is to be reasonable.

A design study of a large boiling-D_2O reactor, utilizing natural-uranium fuel and capable of producing 1000 MW of heat, or a gross electrical output of 270 MW, has been carried out by Argonne National Laboratory. In this design, the fuel elements consist of natural-uranium plates clad with a zirconium alloy (Zircalloy-2), bound together in clusters, and surrounded by a 6-in. diameter Zircalloy-2 tube. Each plate is 0·15 in. thick, including 0·04 in. of cladding. The water passage between plates is 0·35 in. wide. Additional area for coolant flow exists between the ends of the fuel plates and the zirconium tube. The fuel plates are free to

grow downward if they are inclined to do so as a result of irradiation and/or thermal cycling.

The length and total number of fuel assemblies in the reactor determine the power output. It is estimated that in a boiling reactor operating at 600 psia the power output can be about 0·28 MW per foot of length of the fuel assembly. This corresponds to an average heat flux of about 160,000 BTU/hr/sq ft. Thus, for 1000 MW total output, a total of 3550 lineal feet is required. For various reasons, this is divided into 295 assemblies, which, on an 8-in. triangular lattice, form a core about 12 ft in diameter. A D_2O reflector, 1·25 ft thick, surrounds the core. The total weight of uranium is 43 tons.

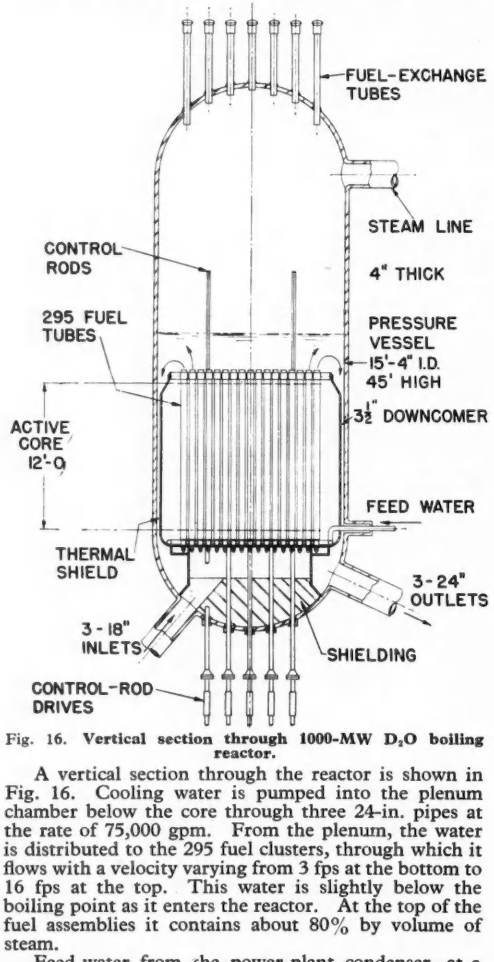

Fig. 16. **Vertical section through 1000-MW D_2O boiling reactor.**

A vertical section through the reactor is shown in Fig. 16. Cooling water is pumped into the plenum chamber below the core through three 24-in. pipes at the rate of 75,000 gpm. From the plenum, the water is distributed to the 295 fuel clusters, through which it flows with a velocity varying from 3 fps at the bottom to 16 fps at the top. This water is slightly below the boiling point as it enters the reactor. At the top of the fuel assemblies it contains about 80% by volume of steam.

Feed-water from the power-plant condenser, at a temperature of 90° F, enters the reactor pressure vessel through a separate pipe and is distributed by a header system in the spaces between the fuel clusters at an elevation just above the bottom grid. This cold feed-water warms up gradually as it rises, owing to absorption of gamma rays and moderation of neutrons and to conduction of heat through the walls of the fuel tubes. By the time this water reaches the top of the core it will have increased in temperature to about 300° F. The average temperature of the moderator and reflector is about 200° F. By keeping the moderator relatively cool in this manner, the resonance capture and the leakage of neutrons are reduced, thereby giving more reactivity and a slightly higher conversion ratio. It is also advisable to keep this moderator below the boiling point, to avoid flashing upon reduction of pressure in the steam dome due to an increase in the steam demand of the turbine. Upflowing streams of water from the fuel tubes and the moderator mix above the core. This slightly subcooled water is then returned through the annular downcomer and the outlet pipes to the circulating pumps.

The reflector thickness below and around the core is 1·25 ft. A portion of the space between the bottom head of the pressure vessel and the lower grid is filled with steel to reduce the inventory of D_2O. Above the core the reflector thickness is increased to 3 ft, in order to minimize the effect of turbulent surface conditions on reactivity. The total weight of D_2O in the reactor is about 100 tons. An additional 20 tons is held up in the power-plant equipment and in reserve storage. The conversion ratio in this reactor has been estimated to be 0·90, with an initial excess reactivity of 2·3%.

A design study has also been made by Argonne National Laboratory of a 250-MW D_2O boiling reactor. The general design is identical with that of the 1000-MW reactor, except that the size is reduced. Fuel elements are basically the same, but their overall diameter has been reduced to 5 in., while the core has been reduced to 7·5 ft, and the total uranium content to 11 tons. In this 250-MW reactor, the U^{235} content of the fuel is 0·92%, and the initial conversion ratio is 0·87, with an excess reactivity of 2·2%.

The net result of decreasing the reactor from 1000 MW to 250 MW and enriching the fuel is to increase the combined fuel and D_2O costs per kWh by between 50 and 75%. That this 250-MW reactor is still attractive from an economic standpoint has been shown by comparison with an H_2O boiling reactor with the same output.

A preliminary study of an experimental pressurized heavy-water reactor for a heat output of 10,000 kW and a generator output of approximately 2500 kW has been carried out in Norway, and is based on the findings of the joint Dutch-Norwegian staff at the Kjeller Reactor Establishment and a group in the Chr. Michelsens Institute in Bergen.

The Brookhaven Liquid-Metal Fuel Reactor:—

An interesting reactor design, which uses liquid fuel in the form of a solution of uranium in bismuth, has been proposed by the Brookhaven National Laboratory, to produce 210,000 kW of electricity. In this plant, a high thermal efficiency is achieved, as the U-Bi fuel in the reactor will produce steam at 482° C and 88 kg/cm². The U^{233} used in the fuel solution is produced in the reactor from thorium which surrounds the reactor core in a "breeder blanket". Both the fuel and thorium-bearing fluid are circulated for heat removal and chemical processing.

Fig. 17 shows diagrammatically the principal cooling and processing streams from the reactor core and breeder blanket. The main fuel stream is circulated through a sodium heat exchanger, the sodium carrying the heat to the steam boiler. The thorium-bearing stream is composed of a slurry of Th_3Bi_5 suspended in molten Bi and is also circulated through a heat exchanger for cooling. Volatile fission products are carried by a helium stream from the free surface of the U-Bi solution and stored in traps. A small part of the main fuel stream flows through the processing system, where the fission products are removed and additional U^{233} added. Finally, a process stream flows from the blanket for removal of the Pa and U^{233} (produced in the blanket), as well as fission-product removal.

The reactor consists of a graphite core through which the U-Bi fuel is pumped, an inner graphite vessel which separates the fuel stream from the thorium-bearing breeder blanket, the blanket and an exterior containing vessel to which are attached the inlet and

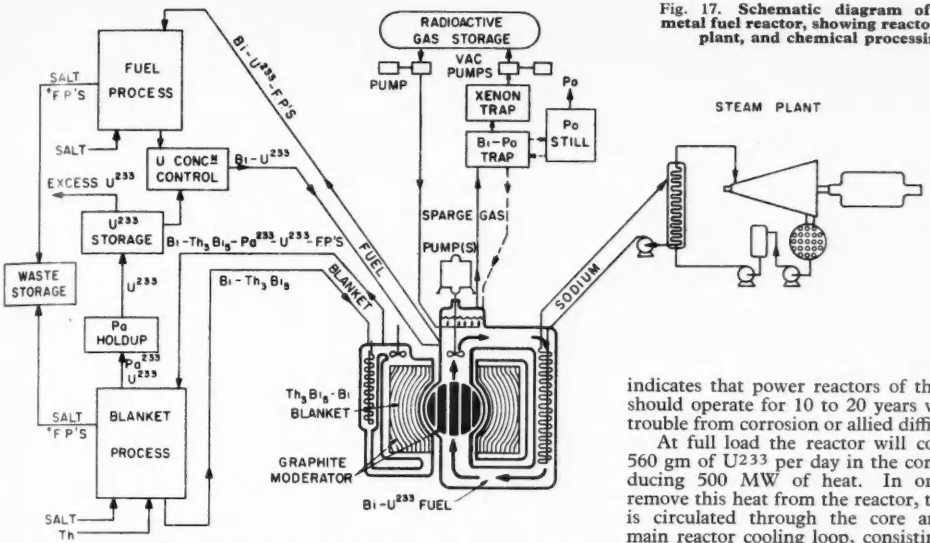

Fig. 17. **Schematic diagram of liquid-metal fuel reactor, showing reactor, steam plant, and chemical processing.**

outlet piping for the fuel and blanket streams. It is desirable to keep the concentration of uranium in the fuel stream low, as a considerable volume is held up in the heat exchanger and external piping. The concentration of U^{233} required to maintain a chain reaction under operating conditions is only 670 ppm by weight.

Graphite was chosen as a moderator; this material was also considered suitable for the interior reactor structure. No reaction between graphite and the uranium-bismuth fuel has been observed at temperatures up to 1000° C with exposures of 100 hours. At higher temperatures, up to 1200° C, there is some reaction. However, in the presence of a few hundred parts per million of Zr there is a preferential formation of ZrC and no evidence of UC is found. On all counts the operation of the reactor with the U-Bi fuel in direct contact with the graphite is quite feasible.

This reactor design uses very small quantities of metallic absorber materials for structural purposes in the core and blanket, resulting in a high neutron economy. The reactor core is pure graphite; the barrel-shaped vessel separating the core fluid from the blanket fluid is, with the exception of the alloy bonding rings, pure graphite. The core is made of a solid right circular cylinder of high-density graphite, 5 ft in diameter and 5 ft high. Under full-load conditions the U-Bi solution enters the core at 400° C. Fission takes place in the core, generating heat rated at 500 MW and raises the temperature of the fuel to 550° C at the exit to the core. The average flux in the core is 10^{15} neutrons per cm^2 per sec. Fuel is pumped directly through the inner vessel and core from bottom to top. The thorium-bismuth slurry is pumped through the blanket, flowing upwards around the rods and out at the top.

The entire graphite core and blanket assembly is contained in a steel pressure vessel, 12 ft in diameter and 15 ft in height. The material used in the container vessel and connecting piping is low-chrome steel containing 2¼%Cr—1%Mo. The chief corrosion problem in a liquid-metal system, such as the U-Bi solution in steel, is that of mass transfer, i.e., the deposition of dissolved metal at the cold region of the circulating liquid-metal stream. This has been successfully solved by the addition of Mg to pick up any traces of oxygen, and of Zr to inhibit both the rate of dissolution of the steel in the high-temperature region and the deposition in the low-temperature region of such systems. Successful operation of experimental loops indicates that power reactors of this type should operate for 10 to 20 years without trouble from corrosion or allied difficulties.

At full load the reactor will consume 560 gm of U^{233} per day in the core, producing 500 MW of heat. In order to remove this heat from the reactor, the fuel is circulated through the core and the main reactor cooling loop, consisting of a 36-in pipe, leading from the reactor core through the U-Bi to a sodium primary heat exchanger to the degasser, to the fuel-circulating pumps, and back into the core. Two 26-in. lines from the chamber, which re-enter the 36-in. return line, contain the main fuel-circulating pumps. This piping is designed to a minimum volume (consistent with allowable pressure drop) for fuel-inventory considerations. The U-Bi hold-up in the fuel system is approximately 867 cu ft. The heat cycle of this system is shown in Fig. 18.

The 36-in. line from the loop of the reactor connects with the U-Bi solution heat exchanger, where the heat is transferred to sodium. Inlet U-Bi temperature is 550° C and exit temperature 400° C. The breeder-

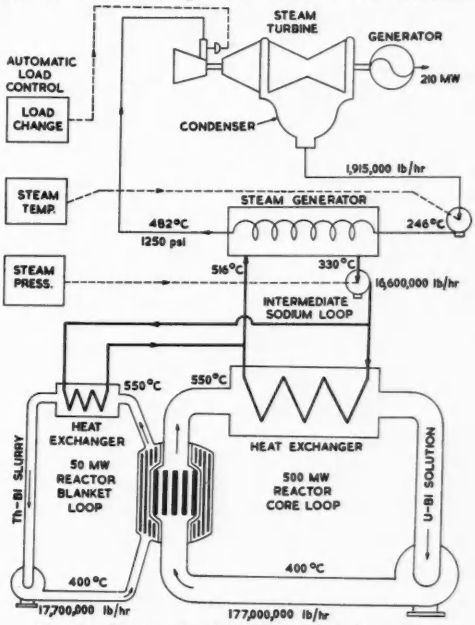

Fig. 18. **Heat cycle of liquid-metal fuel reactor.**

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blanket system contains 746 cu ft. of bismuth containing 10% by weight of thorium in the form of a suspension of Th_3Bi_5. The neutrons leaking from the chain-reacting core produce heat in the blanket through capture of the thorium by fission of some of the U^{233} formed in the blanket. This, plus the heat due to gamma rays and other radiations absorbed in the blanket, is removed by pumping the blanket fluid through a closed loop of the heat exchanger and processing plant in the same manner as the main reactor loop.

A 1250-psi, 482° C steam cycle was chosen, to permit the use of a conservative design of conventional turbine-generator equipment. The 482° C steam temperature provides an ample temperature differential margin below the 550° C discharge temperature of the U-Bi, to permit the use of relatively small U-Bi to Na, and Na to steam, heat exchangers. This arrangement provides full steam temperature to below half-load operation with simplified controls and no operational controls for the reactor.

Because of conditions peculiar to liquid-metal fuel-system operation, the reactor complex requires several unique auxiliary systems, the NaK system, the helium system, and the cooling system for the reactor room. The NaK system maintains the temperature of the uranium-bismuth solution and sodium systems within definite limits, to prevent freezing of the metals, and also provides for emergency cooling of the U-Bi. The NaK system was selected as a cheap and practical arrangement for maintaining the system temperature within the specified limits of the liquid-metal systems. The helium system is devised to pressurize the U-Bi, sodium, and NaK circuits, and to preheat the reactor core whenever it is recharged. The cooling system utilizes closed air circulation to remove sufficient heat from the concrete reactor-room walls and to prevent dehydration of the concrete, with accompanying deterioration of its shielding effect. Air is circulated between the steel lining and concrete walls and cooled externally with spray water. This closed system of air circulation is used to prevent the possibility of discharging radioactive air to the atmosphere.

The breeding ratio of 1·05 will be obtained only if the concentration of fission-product poisoning is kept low by rapid processing. The fuel can be circulated and processed continuously or in small batches while the reactor is in operation.

The fuel is processed in three different ways. The volatile fission products are removed continuously from the main fuel stream. This is accomplished by passing the fuel stream into an evacuated chamber in a fountain which allows the Xe and other volatile fission products to escape. The bismuth and polonium vapours are condensed in a water-cooled condenser. If there is a demand for the polonium it can be distilled from the bismuth; otherwise, it can be remelted and returned to the fuel stream. The fission products are absorbed on charcoal and may be used as a radiation source. Alternatively, the sparging gas is reused or allowed to decay until it can be discharged to the atmosphere.

The non-volatile fission products fall into two groups. The first includes Sr and the rare earths, which form the worst fission-product poisons. This group can be removed by extraction into a fused salt. In order to keep their poisoning effect below 1%, they will be processed continuously at a rate that holds them down to 15 ppm. A small stream of fuel, about 0·5 gpm, is diverted from the reactor and circulated through a counter-current column, where the fused salt stream, consisting of the eutectic mixture NaCl, KCl, and $MgCl_2$, reduces the fission-product concentration to around 5 ppm. Most of the uranium stays in the fuel stream, but a small amount transfers to the salt. This is scrubbed from the salt stream in an upper column, where a small stream of Bi containing Mg reduces the U from the salt into the Bi. This Bi stream flows to a bottom column, where the U is returned to the salt by oxidation with $BiCl_3$. In order to add U to the fuel stream to make up that consumed in the reactor, the salt stream carries UCl_3 into the processing column.

The second group of non-volatile fission products cannot be separated from uranium by the above process. These fission products have much smaller cross-sections on the average and their poisoning effect builds up much more slowly. Therefore, it is necessary to process only at about one-twentieth of the rate required for the salt-soluble fission products. This could be done by a process in which these elements are removed from the Bi with the uranium and then separated. This would also clean out any corrosion products which would have some slight poisoning effect if allowed to accumulate.

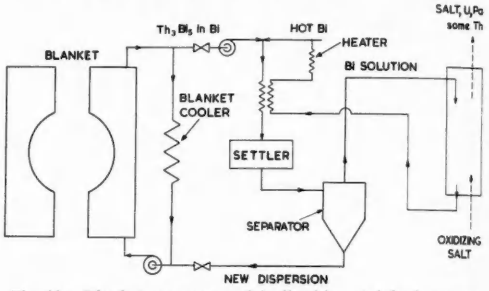

Fig. 19. **Blanket process used in liquid-metal fuel reactor.**

The blanket consists of Th_3Bi_5 suspended in liquid Bi. If the concentration of uranium formed in the blanket is kept below 100 ppm, the power generated by fission in the blanket will be less than 10% of the total. This concentration level can be maintained if the blanket fluid is processed at a rate of 20 tons per day. The processing cycle is shown in Fig. 19. A stream of about 20 gal/hr of Bi containing 10% Th as Th_3Bi_5 is diverted from the blanket cooling system. This is first diluted with an equal amount of pure hot Bi. In order to get the U^{233} and Pa into solution without completely dissolving the Th_3Bi_5 particles, this diluted mixture is cycled thermally between 850° C and 350° C. During this treatment 60% of the solids go into solution and re-form on the undissolved portion of the crystallites, allowing about 30% of the U^{233} + Pa to stay in solution in the Bi. The mixture goes into a phase separator, which concentrates all the Th_3Bi_5 particles into one stream, to return to the reactor. The other liquid contains in solution 50 ppm of Th and 30 ppm U^{233} and Pa, which are extracted from the Bi. The latter is purified and recycled to the processing stream. The Pa is allowed to decay to U^{233} and is available for use as a reactor fuel. Again, the quantity and equipment size are small. For a 500-MW core power, about 550 gm of U^{233} and Pa will be recovered per day.

With regard to the present status of this plant, most of the chemical and metallurgical problems have been solved, and many small loops have operated outside neutron fields. One chemical-processing loop is at present being operated at a flux of 10^{10} neutrons per cm^2 per sec in the Brookhaven reactor. Engineering developments have been started on pumps, heat exchangers, and chemical-processing columns. Exponential assemblies of uranium, bismuth, and graphite will be made in 1956, and it is planned to start the construction of some form of experimental or prototype reactor in late 1957 or 1958. It is believed, however, that construction of large-scale plants of the type described, with a breeding ratio approaching unity, will not be achieved until the early 1960's. Nevertheless, it should be mentioned that no obstacle of a fundamental nature has as yet appeared to stand in the way of eventually operating this reactor and achieving the thermodynamic efficiency, economy, and safety possible with a continuously processed liquid-metal fuel.

(*To be continued*)

Applications and Limitations of Cermets

By R. Steinitz. (From *Jet Propulsion*, Vol. 25, No. 7, July 1955, pp. 326-330, 7 illustrations.)

During the past decade new materials, designated cermets, have been developed on the basis of combinations of metals with refractory compounds. The specific characteristics of some of these cermets and the general requirements for high-temperature materials are discussed in this article, together with indications of the shortcomings of cermets and the probable trend of future development work.

While it is true that a range of so-called super-alloys, with many desirable properties, has been developed for use in engines at temperatures up to 1600° F, they have one shortcoming :—The temperature limit up to which they can perform has been reached, and there appears to be very little possibility of extending their range to higher temperatures by changing their composition slightly or by adding a new alloying element.

In considering temperatures between 1800° and 2000° F at which an engine should be capable of operating for an appreciable period, the immediate thought is, of course, to use metals with higher melting points and to try the refractory metals, tungsten, molybdenum, and tantalum, which have such high melting points that 1800 to 2000° F is a comparatively low temperature in their case. Tungsten and tantalum are, however, so heavy that they cannot be considered for a large number of applications. Furthermore, all three metals are not oxidation-resistant at high temperatures, their oxides being rather volatile and burning away rapidly at temperatures over 1300° F. In the case of molybdenum, which seems to have the greatest chance of success, considerable work is being done to find a protective coating for this metal. Its high-temperature properties at 1800° F are excellent, its heat-shock resistance is very good, and it would be applied immediately if a protective coating could be found.

Another group of materials consists of refractories on the basis of ceramics, which can withstand very high temperatures without dimensional changes and without any variation in their properties. They are mainly oxides and hence are excellent in chemical stability. However, they are so brittle and especially so sensitive to heat shock that they would, for instance, shatter if the ignition in a jet engine were to fail and if cool air were to be sucked into the turbine.

There are, therefore, two distinct classes of materials, one of which is strong at high temperatures but brittle and heat-shock sensitive, while the other is ductile and impact-resistant but loses its stength at the high temperatures required. Cermets are a combination of these classes and already a fairly large number of compositions is available, fulfilling one or more requirements of engine designers.

The following cermet materials have up to now aroused the greatest degree of interest :—(a) Titanium carbide, with a nickel or cobalt binder, or with nickel alloys with chromium, molybdenum, or aluminium ; (b) boride-base materials, with or without the addition of materials such as chromium or nickel, using zirconium boride, chromium boride, and molybdenum boride as the refractory components ; (c) silicide materials on the basis of chromium or molybdenum disilicide ; (d) aluminium oxide and chromium materials.

Despite this variety of materials, the possibility of combination is not as large as would appear on the basis of available compounds, especially if it is taken into account that most of the metals form a large number of borides and silicides with quite distinctive properties. The idea of the construction of cermets was to combine the metallic properties of the binder material with the refractory properties of the hard-metal part. This consideration is, however, a simplification which is rarely or never quite correct. In the first place, the two components react at high temperature to such a degree that, in a number of cases, new substances are formed which may have unknown or even undesirable properties. In the second place, the properties of such a compound material cannot be considered as the sum or the average of the properties of the individual materials. Reactions in the solid state occur not only at the high sintering temperature, but may also occur or continue to occur at the service temperature, which is supposed to be in the neighbourhood of 2000° F. Reactions in the solid state are quite rapid at these high temperatures, and the often-mentioned advantage of powder metallurgy to produce non-equilibrium structures is no longer usable if the part has to be held at such high temperatures for a considerable time. It should be remembered that solid-state reactions occur even at room temperature. Very clean metals stick together at room temperature to such a degree that intergranular fractures occur if clean metal surfaces are brought into close contact and separated again.[1] Friction at room temperature between unlubricated surfaces largely consists of such a solid-state welding between two surfaces in close contact. At high temperatures this welding process occurs at a highly accelerated rate. This, of course, constitutes the sintering process. Similar diffusion processes can produce new compounds or new materials which are different from the starting materials. The binder metal contained in the final product has properties which are different from those of the pure metal itself. This is caused by the state of high stress under which the binder is maintained, owing to the presence of the large amount of hard particles dispersed in it, preventing deformation of the metal phase.[2]

The reactions which occur at a high temperature in cermet preparations quite often determine the selection of the production method for these materials. If the amount of liquid phase formed is very high, hot-pressing would act to squeeze out some material, so that the final composition is low in binder metal. This would be hard to control and depends to a large degree on the temperature at which hot-pressing is performed, so that cold-pressing and sintering procedures are preferable. In the latter case, time and temperature can be controlled so well that the product will be reproducible. If reactions with the formation of new compounds occur, hot-pressing again is not to be recommended, as it does not assure that equilibrium is obtained. In such circumstances the reactions would continue at the service temperature and would usually involve dimensional changes, as well as changes in properties. On the other hand, if the metallurgy of a cermet is well understood and equilibrium conditions are assured, hot-pressing is a method which can rapidly produce large numbers of small samples with the highest properties usually obtainable in a composition.

The Most Common Cermet Materials

The hard metal or metallic refractory which is most common for cermet application at present is titanium carbide. Titanium carbide has only fair oxidation resistance, and two methods have been applied to improve the scaling resistance. One is the addition of other carbides, TaC and NbC, which form solid solutions with titanium carbide and considerably improve the resistance to oxidation.[3] To these solid solutions, nickel or nickel alloys are added, giving some ductility to the cermet and making it possible to produce it at convenient sintering temperatures. The second method is to add chromium to the nickel binder phase and thereby improve the oxidation resistance.

Many variations in these compositions have been tried, in order to improve behaviour at high tempera-

tures. Generally, the strength is adequate and so is oxidation resistance, but the materials are still quite brittle, especially at room temperature, and the problem of improving the impact strength is not yet solved. Other materials consist of chromium boride or zirconium boride, with or without the addition of binder metals, such as chromium, and these materials have shown exceptionally high strength values at very high temperatures. They are also quite brittle but will, it is believed, form the basis for new materials, if temperature requirements still higher than 1800° F will be required.[4] Another material with high hardness has been produced on the basis of molybdenum boride and nickel. Though this material is not directly applicable for high-temperature use, because of the lack of oxidation resistance, it illustrates the reactions which can occur in the preparation of these materials. The material has found some application as a new cutting-tool material and is prepared from molybdenum boride and nickel.[5, 6] If these two substances are mixed together and heated to sintering temperature, they react together to form a new compound, Mo_2NiB_2, which, fortunately, has quite desirable properties for a cutting-tool material.[7] The liquid phase is furnished, not by nickel, but by a eutectic which is formed by the new compound Mo_2NiB_2 and the left-over of Mo_2B material. The reaction can be closely controlled without much difficulty, and the material has a number of applications which are quite interesting.

The combination of borides or silicides with their parent metals (e.g., chromium silicide + chromium) is also a possible method of producing cermets. However, it should be kept in mind that this is only possible for the lowest compound formed in the system. Chromium and silicon, for instance, form at least four different compounds together, and if chromium were added, for instance, to chromium disilicide, a reaction would occur forming a lower silicide, rather than preserving the combination of disilicide and chromium as a cermet material. Cermets on this basis have been produced and are being investigated for their physical properties and their stability at high temperatures. Chromium-base materials have the advantage of being excellent in oxidation resistance; however, they are usually exceedingly brittle.

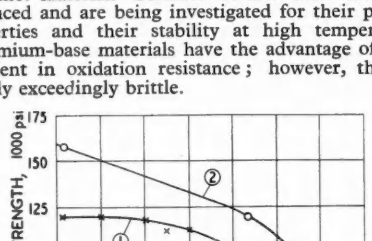

Fig. 1. **The strength of cermets as a function of temperature.**
(1) 80% TiC/20% Co. (2) Non-cemented TiC.

The properties required for a high-temperature material are high tensile strength, low creep, high stress-to-rupture strength, good heat-shock resistance, low oxidation, and the highest possible impact resistance against mechanical shock. A characteristic change of strength with temperature[8] is shown in Fig. 1. Stress-rupture data[4] are given in Fig. 2 and show the life under load for a certain material at a certain temperature. For a 100-hr life, stresses of 12,000 to 25,000 psi can be

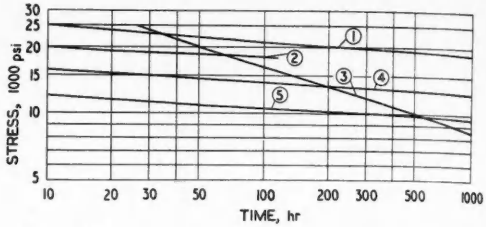

Fig. 2. **Stress-to-rupture data for a number of cermets.**
(1) ZrB_2-base cermet. (3) TiC-base cermet.
(2) Coated molybdenum. (4) Cr_2B-base cermet.
(5) Super-alloy.

obtained at 1800° F. This is satisfactory for almost all applications. The oxidation resistance is considered satisfactory if the samples can withstand tests for 100 to 300 hr under stress in these stress-rupture tests. The heat-shock resistance of most materials is also quite good, and 2000 cycles from 1800° F to room temperature in a rapid change have been withstood by a large number of these materials.

Impact Strength

The property which is still preventing the wide application of these new high-temperature materials is their impact strength at room and at high temperatures. In some cases the high-temperature impact resistance is considerably better, but this is the exception rather than the rule. The impact resistance of the best cermet materials available is roughly only 20% of some of the super-alloys, which may even be considered brittle if compared with the ordinary metals. A lot of work is being done at present to improve this impact resistance. One obvious way would be to increase the binder content; however, with up to about 70% binder and 30% hard metal the improvement in impact resistance is so small that the loss of stress-to-rupture strength is not justified. Another way, started only recently, is the control of the microstructure of these cermet materials by special treatments, which, however, are still far from understood. The reason for this requirement of relatively high impact strength is that foreign particles can occasionally fly through a jet engine and would shatter the blades if they were made of a low-impact material. This is a serious problem, and the success of using cermets for turbine applications will depend on its solution. Even though a large amount of time is being spent at present to make cermet materials less brittle, it seems beyond doubt that the designer of high-temperature engines will have to take into consideration the use of materials which are more brittle

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than those he is accustomed to work with at present. For stationary applications, some cermets would be usable immediately, if the impact requirements are not too high. Here, however, the competition of the cast and wrought super-alloys is quite strong and the superiority of the cermet material not so pronounced.

Conclusions

New and stronger materials, and materials with better impact strengths, are being developed constantly. It is, however, not to be expected that materials will ever be created which are comparable with the super-alloys in impact behaviour but which have a higher temperature limit. With the constant demand for higher operating temperatures, the designer of engines must realize that he must change his standard way of thinking. The use of brittle materials seems to be unavoidable if the service temperature has to be raised. For short-time applications such as rockets, some of the present-day materials may be immediately applicable. Competition in this field with standard ceramic substances is strong. For rotating parts and machinery in which close dimensional tolerances are required at high temperatures, the present design and materials do not as yet fit together. Even if cermet blading for an engine could fulfil all requirements for a rotating part, the shaft and the bearings would probably become considerably overheated, owing to the high heat conductivity of the cermet materials which, in turn, makes them insensitive to heat shock. The metallurgist is trying to come closer to the requirements of the present-day designer by the development of materials with better impact resistance. On the other hand, the designer will have to consider the use of more brittle materials, especially if he wants to push the temperature frontier beyond the 2000° F limit into the range of 2400 F or still higher temperatures—the likely goal for the combustion engines of the future.

GERMANY

Investigation of Fractures in Sintered Materials with the Electron Microscope

By H. Pfisterer. (From *Siemens Zeitschrift*, Vol. 29, No. 5/6, May 1955, pp. 199-205, 13 illustrations.)

As sintered products, owing to the nature of both the production process and the substances employed, are relatively brittle, they require different methods of investigation from those used for ductile metals or alloys. This is particularly true in the case of microscopic structural analysis.

In the metallurgical interpretation of the term "structure" as the sum total of the size, shape, and arrangement of all the components of a sintered material, the optical investigation of such a fine structure demands the use of a microscope with higher resolution than conventional optical microscopes. In short, an electron microscope is essential, as the image it produces presents two advantages which are of the utmost importance, particularly in the investigation of either the free surfaces or fractures of such materials, i.e., higher resolution and greater depth of focus.

The advantages of higher resolution are obvious. The greater depth of focus, owing to the small aperture of the electron microscope (about 10^{-3} in normal work as against approximately 1 for high enlargement in the optical microscope), makes the reproduction of rough and irregular surfaces worth-while, even with a magnification of only about 1200, and produces stereoscopic and highly plastic images of the fractures, conveying an excellent spatial impression.

The highly brittle ceramic, oxide-ceramic, and metal-ceramic materials present an extensive field for investigations of coarse and fine fractures of this type. Whereas, in substances with fine crystals, the fracture preferentially takes an intercrystalline course along the grain boundaries and cleavage planes, in coarse-grained substances it affects the grains themselves, producing therein various structures, from the course and formation of which many interesting specific conclusions can be drawn.

Two types of structural images can be distinguished, i.e., images showing natural defects in the crystals and the crystalline structure, as exposed by the fracture; and images appearing only in the course of the fracture or cleavage.

The former mages are the more interesting in structural analysis. In favourable cases it is possible to draw the same conclusions regarding structure as those which could be derived from conventional metallographic examination. Moreover, the stereoscopic technique permits spatial determination of the shape and distribution of the crystals, clearly showing the density of a ceramic shard. As the fracture surfaces are not subjected to mechanical or chemical treatment, they escape the undesirable changes involved in the production of finished sections of hard, brittle substances. The finishing of specimens of ceramic testpieces, particularly those of sintered hard metals, is so difficult that the preparation of replicas for the electron microscope is simple by comparison. Moreover, before preparation for the electron microscope, the primary replica can be checked or viewed in transmitted light in any optical microscope.

Investigation of Ceramic Materials

The suitability of the electron microscope for investigations of fractures has been demonstrated by the Triafol-SiO process on a sintering of barium titanate, which crystallizes into the distorted perovskite (calcium titanate) type. In this two-stage process a negative of the surface is taken by pressing onto it a superficially dissolved acetobutyrate foil (Triafol BN). This matrix is too thick for electron irradiation, and is therefore given, by vapour deposition in a high vacuum, a layer of SiO, approximately 0·01 μ thick, and is then dissolved in an organic solvent. The remaining SiO positive is transferred to the specimen holders and is photographed in the electron microscope.

$BaTiO_3$ is usually produced by first converting $BaCO_3$ and TiO_2 into $BaTiO_3$ at temperatures around 1000° C, then sintering the pressings made therefrom at temperatures between 1250 and 1350° C. The $BaTiO_3$ —primary grain-size 0·2 to 0·5 μ—is made into a paste with a binder, and is then shaped, dried, and sintered.

Fig. 1 shows the characteristic normal development of a sintered series. In the initial sintering stage, each grain is individually distinguishable, being separated from its neighbours by interstices of varying width, determined by the grain shape and size, the compacting of the grains after pressing, and the volatilized binder (in the simplest case, water). With increased sintering times and temperatures the average size of the still individually distinguishable grains also increases, while the number of pores decreases, their rounding off and coalescence being clearly apparent in the image produced by the electron microscope. The decrease in their

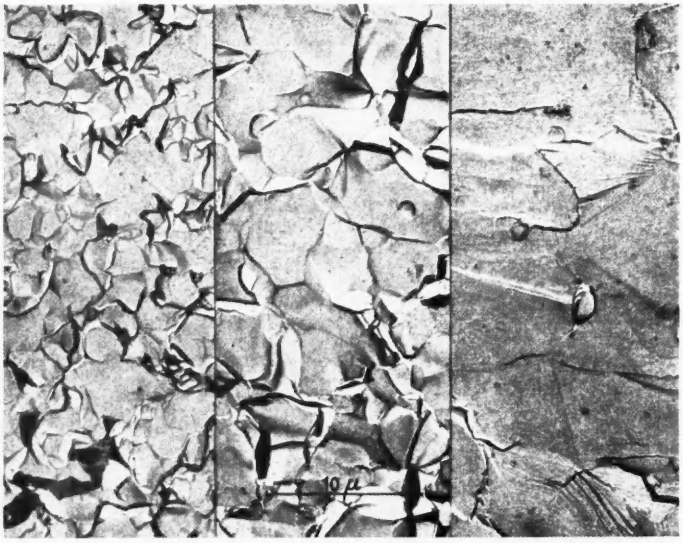

Fig. 1. **Normal growth of $BaTiO_3$, showing fractures of three samples sintered at (left) 1250° C, (middle) 1300° C, and (right) 1350° C.**

total volume may be regarded as a yardstick of structural densification, provided that the statistical mean can still be expected from the area covered by the electron microscope, i.e., with a mean grain size up to 5 μ.

As shown in the section at the left of Fig. 1 (sintering temperature 1250° C) the mean grain size is about 1·5 to 2 μ. Each grain, however, is still individually visible, with its own boundaries. The pores appearing as dark tubular structures are already largely rounded off.

In Fig. 1 (middle)—sintering temperature 1300° C, grain size 4 μ—further densification is reflected by the decreased number of grain boundaries. The rectilinear crystal boundaries have become considerably rounded, so that the crystals cling together closely.

The right-hand section of Fig. 1 (sintering temperature 1350° C) shows portion of a highly sintered structure, with typical deformation structures and with the grain boundaries only just apparent.

Where grain growth is inhibited, the process is as shown in Fig. 2. No appreciable growth occurs up to a certain sintering temperature and period; there is then a sudden onset of intense growth in individual crystals, the proportion of which rapidly increases. The left-hand section of Fig. 2 (sintering temperature 1250° C) still shows a grain size of 0·5 μ. However, the difference, as compared with the structure in normal growth at the same temperature (Fig. 1, left), is obvious. The pores are of an entirely different character, owing to the smallness of the crystals and their clustered arrangement. The absence of rounded pores, like the smallness of the crystals, indicates that no superficial fusion or any considerable grain-to-grain diffusion can have taken place. At a temperature of 1300° C (Fig. 2, middle), a very dense structure appears, with recognizable primary crystals of about 0·5 to 1·0 μ. Continued sintering (Fig. 2, right, temperature 1350° C) produces very large crystals with a grain size of 30 to 50 μ, the fractures being largely similar to those of normal sintering (Fig. 1, right).

Heterogeneous phases can be demonstrated in frac-

Fig. 2. **Inhibited growth of $BaTiO_3$, showing fractures of three samples sintered at (left) 1250° C, (middle) 1300° C, and (right) 1350° C.**

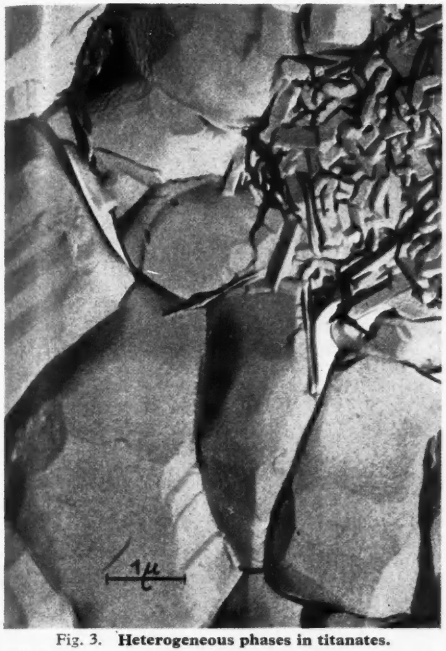

Fig. 3. **Heterogeneous phases in titanates.**

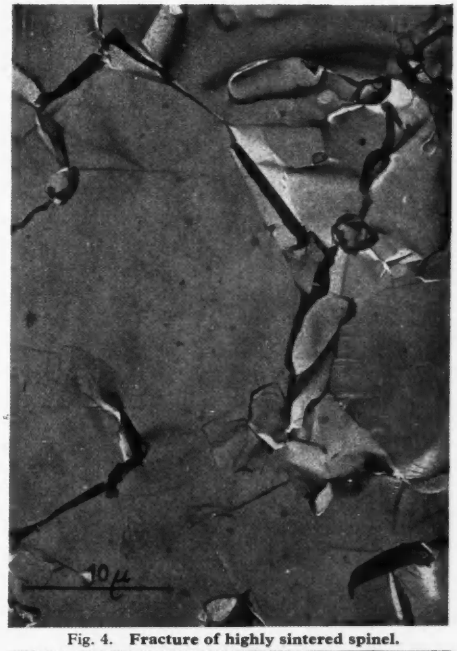

Fig. 4. **Fracture of highly sintered spinel.**

Fig. 5. **Fracture of spinel, showing laminated structure.**

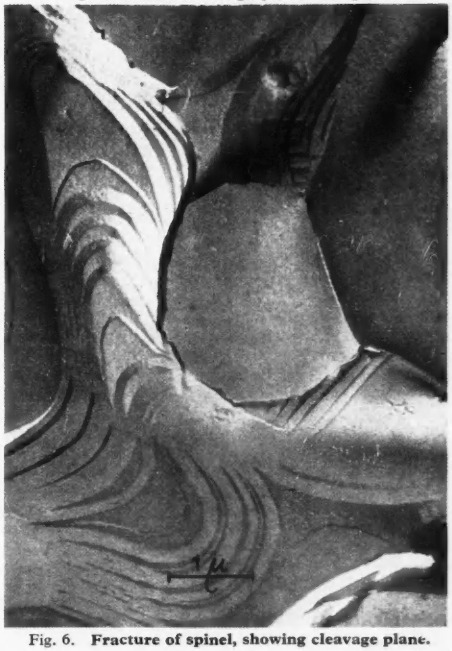

Fig. 6. **Fracture of spinel, showing cleavage plane.**

tures and surfaces (Fig. 3), but "inclusions" in the crystals can be detected only in the fracture. With practice it is possible, though not easy, to distinguish and identify the various phases in the unetched fracture, instead of in an etched specimen. In the example (Fig. 3), slight heterogeneous non-perovskitic admixtures could not be demonstrated, but it was found possible to fix microscopically the heterogeneous phase in the fracture and the surface, and to determine its distribution in the individual layers.

A uniform structure is naturally of great importance in the production of high-dielectric condensers. Such production can be supervised with the aid of unetched fracture examinations by the Triafol-SiO process; as a result, defective charges can be noted and the causes of the defects rapidly traced.

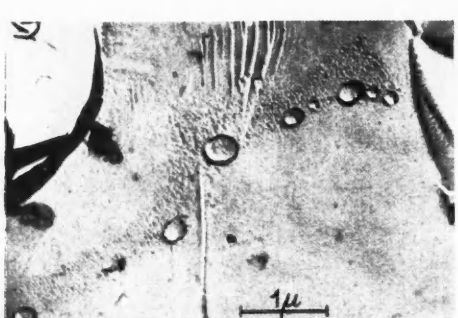

Fig. 7. **Fracture of spinel, showing incipient formation of new pores.**

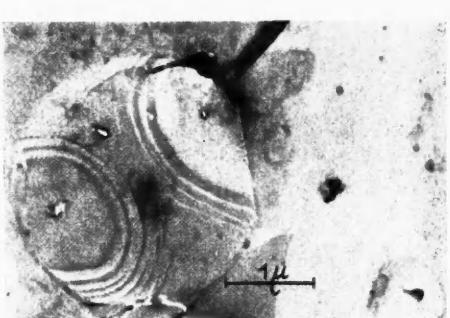

Fig. 8. **Fracture of spinel, showing growth of laminae in the recrystallization pores.**

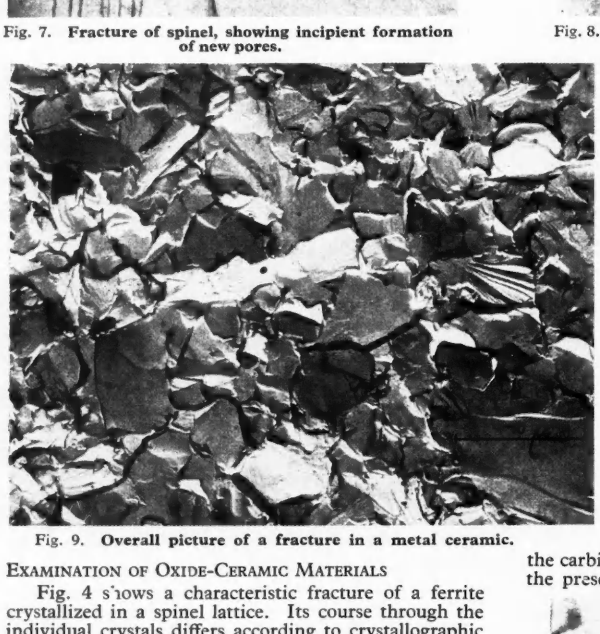

Fig. 9. **Overall picture of a fracture in a metal ceramic.**

EXAMINATION OF OXIDE-CERAMIC MATERIALS

Fig. 4 shows a characteristic fracture of a ferrite crystallized in a spinel lattice. Its course through the individual crystals differs according to crystallographic orientation. Where cleavage or adjacent planes are affected, the surfaces are very smooth and even; in an unfavourable position in relation to a cleavage plane, bowl- and shell-shaped fractures, or deformation structures characterized by parallel, bifurcating fracture lines, preferentially at the edge of the crystals, appear.

The crystal of spinel at the left of Fig. 5 was fractured in a particularly favourable crystallographic direction, so that the laminated structure can be clearly seen. The two crystals at the top right of Fig. 5 show a characteristic spherical bowl type of fracture. The plateau in the middle of Fig. 6 may be regarded as a cleavage plane, owing to its smoothness.

Fig. 7 shows the smallest spherical pores in the middle of the old crystals, which lie in rows behind each other. During further growth these pores remain spherical up to 1 μ, then individual rounded-off surfaces develop. Fig. 8 shows, next to a micropore, a larger pore on whose first crystal plane further laminae have grown. The inhomogeneity in the middle is not unique and is present in many pores of this size.

EXAMINATION OF METAL-CERAMIC MATERIALS

Fig. 9, an impression of a metal ceramic bred for fine grains (78% WC, 16% TiC, 6% Co) shows the eminent suitability of the electron microscope for the investigation of these very complex materials. Whereas the optical microscopic examination of metal ceramics has had to be confined to porosity, fineness of grain, and structural uniformity, it is now possible to make definite observations on the shape and structure of the carbides. In the overall picture shown in Fig. 9, two types of crystals can be clearly distinguished, one of which, with grain sizes of from 3 to 10 μ, preferentially shows angular shapes (WC-TiC = tungsten carbide with dissolved titanium carbide), while the other presents rounded, tightly packed broken crystals with fractures frequently possessing radial striations (TiC-WC = titanium carbide with dissolved tungsten carbide). Cobalt, the binder, is indicated only at some points in Fig. 9. Still higher magnification (Fig. 10) gives the impression that the carbide components have been pressed into a pasty mass of cobalt or mixed-crystal Co-WC. Very narrow grain boundaries can still be detected in this binder phase, which is mostly less than 1 μ wide, suggesting that the cobalt is solidly welded with the carbide lying in it. The bowl-shaped beads suggest the presence of several diffusion areas.

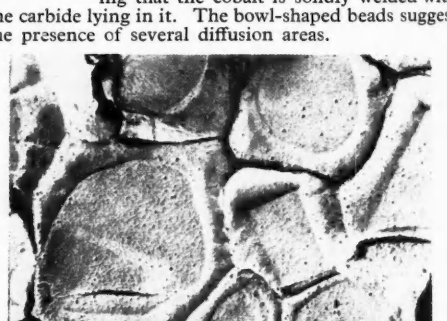

Fig. 10. **Fracture in a metal ceramic, clearly showing the cobalt binder.**

As shown in these different oxide-ceramic and metal-ceramic examples, the Triafol-SiO process is highly suitable for the investigation of fractures and has already produced notable results. Although the resolution obtainable with the electron microscope (< 20 Å) and with the Triafol-SiO process (< 200 Å) was not exploited in all cases, investigation by this means, in view of the considerable depth of focus, represents an important advance in the analysis of sintered materials.

Electro-Machining Methods for Metals

By A. L. LIVSHITS and V. Ya. RASSOKHIN. (From *Stanki i Instrument*, Vol. 25, No. 11, November 1954, pp. 12-17, and Vol. 26, No. 1, January 1955, pp. 8-12, 8 illustrations.)

By electro-machining methods for metals is meant those methods in which the removal of metal or modification of the structure of the surface layer of the material takes place as a result of the thermal, chemical, or combined thermo-chemical action of an electric current, supplied directly to the material and the tool, thus dispensing with the intermediate stages of conversion of the energy of the electric current into mechanical, thermal, electromagnetic, and other kinds of energy.

The following, not including the electrolytic method, which is not considered here, are the basic methods for the electro-machining of metals :—

Method	Nature of the action of the electric current	Field of application
Electric spark Electric impulse	Thermal	Metal removal, coating, and surface hardening
Anodo-mechanical	Thermal and chemical	Metal removal
Electric contact	Thermal	Metal removal
Electro-mechanical	Thermal, combined with mechanical action	Metal removal

In addition, various combinations of the basic methods are known, especially combinations where, at the same time or in succession, both the thermal and chemical action of an electric current are used.

Conditions for Carrying out Electro-machining

To ensure a high quality of machining of metals, using the heat action of an electric current, the following three basic conditions must be fulfilled :—

(1) The electrical energy must be supplied to the area for machining in the form of an impulse of sufficiently short duration.

When the energy is supplied continuously, accuracy of machining is lost, causing a badly fused underlayer, the surface loses its finish, there is a sharp drop in performance, and one of the basic technological qualities of electrically aided machining—the capacity for reproducing the shape of the tool in the material—is lost.

(2) The area of the component to which the energy impulse is applied must be sufficiently small.

When the energy impulse is applied to a large area it is necessary to raise the energy of the impulse accordingly. The greater the molecular removal of metal, then, in fact, the less clean is the surface and the less accurate the machining.

(3) The energy impulses must be supplied directly to the molecular areas of the volume of metal to be removed, and with sufficient frequency. This condition ensures the continuity of the process and the required performance.

Electro-machining methods, based on the thermal action of an electric current, satisfy these three conditions to various extents.

Three ways in which the energy of an electric current may be supplied to the surface being machined are as follows :—

(a) *The energy is supplied through contact between the tool and the material* :—

Contact takes place, not over the whole surface of the tool and the material, but on microscopic irregularities. The electric current I creates heat Q in the contact area of resistance R_c

$$Q = 0{\cdot}24\, R_c I^2$$

As shown by calculation and experiment, with the contact method and the consequent low amount of contact resistance, the energy appearing in the molecular volume heated by the current passing through it (Joule heat) is small in comparison with that required, and is insufficient to melt this volume. In addition, localization of removal to the molecular area of the component is more difficult, since at the same time there are many micro-projections in the neighbourhood.

The method of supplying energy by contact is employed in combined electrical and mechanical machining.

(b) *The energy is supplied over an electric discharge channel—short arc* :—

The short arc created in any method between micro-projections on the tool and the material has an extremely high temperature, reaching 4000 to 10,000° C. In this case the power in the molecular volume is considerable, since the fall in tension on the arc, determining the amount of this power, is ten times higher than with the contact method.

Where the arc is of small diameter, and because there can be only one discharge channel between the interacting surfaces of the tool and material at a given time, the second condition for machining is fulfilled, i.e., concentration of the energy into the molecular areas. In addition, the short electric arc has an important characteristic :—It is possible to carry out the process in such a way that the sequence of arc discharges takes place at points very close to each other on the interacting surfaces of the tool and the material. It is clear, then, that in this way the shape of the tool surface will be reproduced in the part being machined.

Supplying the energy over a discharge channel is widely employed in the electro-machining of metals.

For the first condition of machining to be fulfilled, it is necessary to have a special source of supply, to provide the impulse potential to the tool and the material, i.e., an impulse generator. The third condition is fulfilled by using an impulse generator of the required frequency and an automatic feed control.

To achieve continuity of the process, the gap between the interacting surfaces of the tool and the material should not exceed certain limits, corresponding to the potential at which breakdown of the gap can occur, and constant heat from the arc can be maintained. Consequently, there should be a feed of either tool or material based on the removal of metal, compensating the erosion of both electrodes. This function is fulfilled in electro-machining equipment by the automatic feed control.

(c) *Combined supply of energy* :—

With the method using a combined supply of energy, the process is initiated by contact machining; then, the surfaces of the tool and the material are adjusted to break the contact and produce an arc discharge. With this method, the possibility of reproducing the shape of the tool is limited. Localization of the molecular removal is achieved by contacting micro-projections; continuity of the process and the effectiveness of metal removal are determined by the work of the automatic feed control and the choice of definite rates of relative movement.

Generation of Current Impulses

In electrical generation, a special device or mechanism generates current impulses of the required amplitude, form, and length; in mechanical generation, the current impulses occur as a result of the constant relative movement of the tool and the material (rotation, vibration, etc.).

(a) *Electrical Generation* :—

There are two types of impulse generators, i.e.,

those with dependent characteristics and those with independent characteristics. Generators with dependent characteristics are those in which the frequency, amplitude, and length of the impulses depend on the physical conditions of the machining gap, i.e., the distance between the electrodes, the degree of saturation of the gap by swarf, etc. In other words, the machining gap becomes one of the parameters determining the basic characteristics of the generator and is integral with it.

Dependent relaxation generators suffer from a series of major drawbacks :—

(1) Possible degeneration of impulse currents into a continuous current. An increase in the impulse power and, as a result, in output, causes a shorter pause between impulses, until it almost disappears ; in this case, there is uninterrupted direct current in the machining gap, and machining is retarded.

The limiting speed of metal removal obtainable with powerful single-head machines, does not exceed 1000 mm^3/min at frequencies of 100 to 300 pulses per second.

(2) Low efficiency. Converting alternating current of supply frequency into the direct current necessary to supply the relaxation generators, and then further converting this direct current into impulses, leads to great energy losses in the rectifier (20 to 30%), in the ballast resistance (more than 50%), and in the discharge circuit.

Losses in the generator itself have not been eliminated, and this limits the prospects of possible improvement in the efficiency of relaxation generators.

(3) Dependence of the impulse and frequency parameters on the physical state of the machining gap.

When there is a change in the area and depth of machining, or in the conditions of evacuation of particles and gases, when the steady work of the feed control is interrupted, there is a rapid change in the amplitude, length, and frequency of the impulses and, as a result, the technological characteristics, i.e., output, surface finish, and accuracy, are also affected.

(4) Alternating-current impulse. Relaxation generators, in view of unavoidable inductance in the discharge circuit (wires, condensers, etc.), create an impulsive alternating current, i.e., in addition to positive half-waves, the current impulse has at least one reverse half-wave. This leads to a reduction in the stability of the process and to further tool wear.

The main drawbacks mentioned in connection with dependent relaxation impulse generators show that they do not offer much promise for obtaining large amounts of metal removal. As other sources of impulse current are developed, the field of application of dependent generators in the range of medium operating conditions will be limited. Obviously, this type of generator may be suitable in special cases, especially in forming fine apertures ; in this case the efficiency is not of great importance.

In recent years, a new type of generator, of the impulse type, has been evolved, the main difference between this type and relaxation generators lying in the fact that the type of impulse (amplitude and length) and its frequency are independent of the physical state of the machining gap. The impulse and frequency parameters produced by this source of current cannot change freely, and this at the same time permits wide control of working conditions.

There is no practical limit to the impulse current. As a result, large amounts of metal removal can be obtained per unit of time. Thus, this generator, far from being marginal in its capacity for drilling and copying, attains a removal of 6000 mm^3/min, i.e., six times greater than the maximum obtained with the dependent relaxation generator. The rate of removal, depending on the characteristics of the machine, may reach far greater levels than those obtained by electro-spark methods.

The second great advantage with these new generators is that it is possible to create fully rectified current impulses of the most favourable type. As a result, there has been a sharp rise (5 to 20 times) in the life of the tool. Furthermore, generators of this type can be produced with efficiencies of 73%, i.e., 3 to 5 times higher than those of dependent relaxation generators.

The cost of the plant, i.e., the machine itself and the impulse generator, calculated per unit of performance, is considerably reduced, as, too, is the amount of electrical apparatus required.

Just as there is intensive development of new systems for impulse generators, so the main field of application for these widens. At the present time it is undeniable that they are suitable for use in high- and medium-powered machines, when account is taken of the wide range of working conditions required.

Electrical generation of impulses is the best way of ensuring that the shape of the tool is reproduced in the material. Thus, in the great majority of cases, machines for copying and reproducing holes are based on electric-impulse generators.

(b) *Mechanical Generation* :—

Mechanical generation has formed the basis of anodo-mechanical and electric-contact methods and appears to be the simplest method of creating impulses. This method of generation should be regarded as a dependent method, since the impulse and frequency parameters depend, in addition to mechanical factors, on the physical conditions in the machining gap, the distance between electrodes, the type of working medium, and its degree of penetration into the gap.

Some modified mechanical generators use direct- and alternating-current supply ; the latter may be single-phase or multi-phase (usually three-phase). Control of working conditions is achieved by varying the supply voltage, or by introducing a ballast resistance.

According to the characteristics of relative movement, mechanical generators are classed as generators with rotating or oscillating tools or work material. Rotation is applied to grinding, tool-sharpening, and cutting operations, while oscillation is applied to slotting operations.

(c) *Combined Generation* :—

This method combines electrical and mechanical generation. However, in this instance the role of the mechanical movement is not so much the generation of impulses as ensuring that the tool passes over the whole of the surface being machined, facilitating removal of the machining products and stabilizing the process. Thus, the rate of relative movement can be made lower than in mechanical generation. This is especially important since, in addition to greater simplicity in design, it is possible to carry out such operations as the grinding of details of small diameter at low linear velocities.

Combined generation forms the basis for carrying out slotting, profiling, and grinding operations, etc., using electric spark and impulse methods combined with surface machining.

Of the generators described, the most promising appear to be the independent impulse generators. However, for these to be suitable, it is necessary further to increase the frequencies (especially for rough machining conditions), to reduce losses, and to simplify the electrical mechanism and design. A series of generators must be built to provide current impulse for the whole range of operations of universal equipment for electro-machining. For special machines it is necessary to develop high-frequency, multi-circuit impulse generators.

Control of the Process

The second specific element for the electro-machining of metals is the automatic feed control, the purpose of which is to ensure continuity of the machining

process, and to maintain the maximum speed of metal removal (for a given generator output).

With low potentials, low currents, or soft electrodes, or where there has not been an optimum choice of the pairs of electrode materials, where there has been an incorrect selection of working media, or where they are contaminated by the machining products, regularity of the process is lost; this takes the form of frequent short-circuiting, lost motion, and scaling of the machined surface. In order to avoid this, it is necessary, in addition to increasing the sensitivity and response of the control, to adapt machining conditions to the requirements of the process, as follows :—Suitable material for the tool and working medium should be chosen, the liquid should be purged of machining products, the electrodes should be vibrated, the working conditions should be adjusted to correspond with the size of the machining area, etc. If the process is maladjusted for any of the above reasons, even the most reliable control will not be able to carry out normal work.

If any break occurs in the steadiness of machining, leading to short-circuiting, the electrodes must be drawn apart. Consequently, in cases where there is no guarantee against short-circuiting, the control must be made reversible.

Controls with flexible feed :—

Examples in this group are electromagnetic and electrodynamic controls. The field of application of these systems is at the present time limited, although, because of its simplicity and reliability, the electromagnetic control now has a wide application. Furthermore, it can be employed to advantage in small and medium machines (bearing in mind the limiting working conditions), as it does not need much electrode movement, and, if necessary, the flexible feed control can be of the simplest possible design.

The electrodynamic control, heavier in design, less reliable in service, and with no advantages in performance, is seldom employed.

Controls with positive feed :—

The great majority of control systems belongs to this group. Controls with rigid feed usually employ for automatic drive an electric motor controlled by a signal, either directly from a sensitive element or through a valve or a magnetic amplifier.

Direct control of the electric motor by a signal, not using an amplifier, can be achieved very simply by the well-known self-balancing bridge circuit. This method has found widespread application because of the simplicity and reliability of the circuit. Its disadvantages include insufficient sensitivity and too rapid a response under all working conditions, breakdown or unevenness in the work being machined, an insufficiently large range of control, and the difficulty of finding a suitable standard electric motor when working on impulse generators of low potential.

When working on impulse generators having little or no ballast resistance in the current impulse circuit, the self-balancing bridge circuit must be supplemented by an amplifier.

An automatic control, which gives an automatic feed in any of the known types of electro-machining devices, is being developed. It has for a sensitive element a special triple-wound series transformer which, without any intermediate amplifiers and without further losses in the current impulse circuit, gives a signal which is easily controllable. The amplifier used is a valve amplifier (or in one of the variants a magnetic amplifier), and the drive is from a shunt-wound electric motor. Such a circuit, being universal, can be fully recommended for medium- and low-powered machines. For small machines the units in the circuit should be used separately to give a signal.

One of the most promising variants of the control is the system using controlled magnetic powder clutches.

In individual cases it is convenient to use a thyratron amplifier, but such systems are less reliable in service.

Factors Affecting Rate of Metal Removal

(a) *Rough machining :—*

With a constant area, raising the current first of all leads to a more or less proportional rise in the rate of metal removal, because the volume of metal melted grows with the increase in impulse energy. Further raising of the current retards the increase in the rate of metal removal and finally causes it to fall. Such a pattern for the relationship of current versus metal removal is explained by the fact that, at a given current density, areas appear in the machining gap, from which the liquid is forced out by gases. In this case the machining process takes place in a gaseous medium which sharply reduces the rate of removal. In addition, the absence of liquid leads to melting of the exposed areas; pitting occurs, as a result of the individual impulses, and the surface is coated with material from the tool.

Thus, for a given area, there must be a certain corresponding optimum current, the magnitude of which is determined for practical purposes by the appearance of melted areas, coating, and breakdown of the stability of the process.

The relationship between rate of removal and machining area is also similar in character when the current is constant. With an increase in area, the rate of removal grows, since in small areas there is the effect of liquid displacement by gases, disappearing when the current density falls, i.e., on increasing the area. However, at the same time as the area increases, resistance to the evacuation of the particles and gases increases. As the impulse energy is unchanged, the gas pressure and the power impulse arising in the metal particle being evacuated remain the same. Consequently, on reaching a given area, the time will come when part of the swarf cannot be removed from the machining zone.

Resistance to the evacuation of swarf is affected, not only by the size of the area being machined, but also by its shape. The process of evacuation of swarf may be represented by two components, i.e., a horizontal and a vertical component. The horizontal component, or the " evacuation radius " ρ, depends on the shape of the surface being machined, of area S, and may be determined from the expression :

$$\rho = \frac{I}{S} \int_0^S x_m \mathrm{d}S \qquad (1)$$

where x_m is the minimum distance traversed by the particle in the horizontal direction, and $\mathrm{d}S$ is the molecular area.

For a circle of radius R the evacuation radius, for example, is

$$\rho' = R/3 \qquad (2)$$

and, for a rectangle with sides a and b ($a > b$),

$$\rho'' = b/4 \qquad (3)$$

The vertical component may be taken as equal to the depth of machining h or the distance from the end of the tool to the free surface. Thus, performance also depends on the two geometric parameters ρ and h, which determine the resistance of the swarf being evacuated. As a result, all data on performance, referring to a given area, must also be referred to the corresponding values of ρ and h.

The curve relating the peak of the rate of removal versus area, determined by the variation in the evacuation radius, is very flat, and only with large areas (and consequently large ρ values) does any noticeable fall in performance begin. The effect of ρ on performance, other conditions being equal, increases at low currents and with large areas.

The interconnection described between the geometric parameters of the workpiece and the electrical conditions determines the method for electro-machining metals.

(b) *Finish machining* :—

In carrying out finishing work, performance will be determined by surface finish. If finish machining takes place at low currents and with a correspondingly low impulse energy, the power impulse used to evacuate the particles may be insufficient to remove the swarf from the machining area, and consequently performance will begin to drop. Thus, if for an area $S_1 > S_2$ the surface finish obtained is H_1, the surface finish H_2 obtained for area S_2 will be lower.

Hitherto, in describing the characteristic electrical conditions used in the electro-machining process impulse current (mean or effective current) has been specified. In actual fact, a given mean current may be obtained from impulses of various kinds and various frequencies. An important parameter in the electrical arrangement is the pause between the impulses and its relation to the length of the impulse. The smaller the pause and the shorter the pulse duration, the lower the current at which melting begins (coating of the workpiece), and as a result the lower the performance obtainable in machining a given area. As far as impulse frequency is concerned, it is therefore quite in order for it to be raised for purposes of finish machining since, on reaching a given class of frequency, performance rises, at a first approximation, in proportion to the frequency, together with a similar rise in the total energy required and the specific energy consumed.

The above-mentioned points concerning the electrical arrangements are true, generally speaking, for all varieties of electro-machining methods for metals. Depending on the type of operation (drilling, profiling, grinding, etc.) and the method of electro-machining employed, corresponding correctives are introduced. Thus, for example, machining with rotating electrodes considerably raises the current density obtainable, alters the size of the area which is melted, and improves surface finish.

Applications of Electro-Machining Methods

Experience accumulated over the last few years makes it possible to list the fields in which the application of electrical methods has been found profitable and fields which are promising for its adoption. Some of these are as follows :—

(a) *Making complex holes (dies)* :—

Electro-spark and electric-impulse drilling and copying machines may be used to obtain specially shaped surfaces, both externally (particularly for forging dies) and internally (surfaces of parts of complex shape). However, both technically and economically, it has been found that the cost of making new dies is much the same on the electrical machines at present available (maximum metal-removal rate 600 to 900 mm^3/min) as it is using the normal mechanical forging method.

The economic effect is observed in repairing the dies. Reduction in the cost of repairing a die by the electric-spark method amounts to 30 to 40% in comparison with the mechanical forging method.

With the adoption of the electric impulse method, with its considerably higher performance and lower tool wear, the effectiveness of making and repairing dies increases.

It should be borne in mind that, in die-making by the use of electrical methods, it is of great importance that there should be production in quantity, since the initial outlay for making the tool is quite considerable.

(b) *Cutting-off operations* :—

A study of technical and economic factors has shown that it is not an advantage to use electrical methods for cutting specimens from medium-carbon steels. The costs of cutting tool steels by electrical and mechanical methods are identical. However, it is certainly an advantage to use electrical methods with steels which are difficult to machine mechanically.

(c) *Profiling hard metal plates and grinding milling-cutters* :—

Investigations have shown that the profiling of hard metal plates and the grinding of hard metal milling-cutters can be carried out successfully by anodo-mechanical, or in certain cases by electric-contact, methods.

(d) *Chip-breaker grooves* :—

An electro-spark method for making chip-breaker grooves on hard metal cutting tools has been widely used. This operation can be satisfactorily performed (both in single- and in multi-head machines), and the equipment required is quite simple, so that its use is recommended.

(e) *Removing broken tools* :—

Great economy of material is achieved by the use of electro-spark apparatus for removing broken taps, etc. from work. Such operations are carried out with portable low-voltage equipment (electro-contact and electric-impulse).

(f) *Making small holes and slots* :—

There are machines which make many thousands of small holes per hour in stainless-steel sheet. Large numbers of slots are also made in this steel. Such operations, carried out on multi-circuit, multi-electrode electro-spark and electric-impulse machines, are in many cases impossible to perform by mechanical machining.

(g) *Grinding* :—

Tests show that electro-grinding of hardened parts made of medium-carbon steel, with the normal grinding allowance, is not more economical than the same operation carried out on the usual abrasive-grinding machines. In cases where the machining allowance is considerably more than the normal allowance for grinding and the type of machining is not restricted by requirements of surface finish, electro-grinding may be found to be more economical than the abrasive-grinding method.

A process which has found wide application in industry is the electro-grinding of various special steels and alloys, especially magnetic steels. The most widespread application of electro-grinding is in machining parts made from metal ceramics. This is due to the fact that abrasive grinding of these materials is an arduous operation and may cause surface cracking. However, it should be borne in mind that, to obtain a good surface finish, the electro-grinding process is very slow (2 to 5 mm^3/min). Thus, at the moment, the electro-process is used only for rough grinding.

Electro-grinding of hard metal cutting tools is not very different from mechanical grinding and has the same shortcomings. Until these shortcomings are eliminated, and the additional time taken on the lathe in getting the cutters ready for grinding is greatly reduced, electric methods for grinding normal cutting tools cannot be said to be satisfactory.

At the moment, electro-machining equipment is being manufactured by a number of firms in Russia as finished units, as test models, or as modernized versions of metal-cutting machines, while individual types are being produced in small quantities. It should be stated, however, that the progress achieved in recent years in improving the technique of electro-machining methods has not as yet been sufficiently reflected in the design of electro-machining equipment manufactured industrially.

The Care and Maintenance of Compressors

By W. WESSING. (From *Der Maschinenschaden*, Vol. 28, No. 5/6, June 1955, pp. 57-63, 11 illustrations.)

The economical and trouble-free operation of compressors depends on the attention given to them by users and on proper maintenance. The object of this article is to indicate the considerations to be observed to obtain satisfactory operation over long periods, these considerations being based essentially on practical experience.

THE operation of compressors should be entrusted to a responsible attendant. For large plants, the most suitable men are craftsmen who have gone through an apprenticeship as mechanics. However, reliability, a sense of order, and cleanliness are the best recommendations, though good hearing is also essential, since most troubles first become noticeable through abnormal noise conditions. When a new compressor is erected, the future attendant should work with the fitters so as to become conversant with details of the installation.

ERECTION AND SUPERVISION OF COMPRESSORS

It is preferable to erect compressors in a separate room instead of having them operating in premises where general manufacturing work is being carried out. In this way disturbance due to external noises is avoided and supervision is made easier. Damp or dusty locations are definitely unsuitable. Compressors used for open-air work or operating in unheated premises should be drained when there is danger of frost or should be protected with anti-freeze agents.

Routine operation and maintenance schedules for compressors should be clearly displayed in the vicinity of the compressors. This notice should provide all important information on starting and stopping, as well as on routine checks to be made during normal running. The instruction manuals themselves, provided by the makers, should not be used for this purpose, as they are usually too voluminous and not sufficiently specific.

In the first place, it is necessary to ensure that proper lubricating conditions are maintained at all times. The oil should be selected in accordance with the recommendations of the compressor suppliers. Gum deposits on valves and piston rings or oil-crust formations indicate an unsuitable oil. In many compressors the use of a single grade of oil is insufficient. Thin oils are required for parts operating at low pressures, high speeds, and low temperatures, whereas thicker oils are needed for high pressures, slow speeds, and high operating temperatures. Expensive and high-quality oils should not, however, be used for minor applications. The oil should be carefully stored and protected from dust. In factory premises it is convenient to install oil containers fitted with delivery taps or cocks, with the oil grade clearly marked on labels provided on the containers. To avoid any confusion, it is also useful to identify corresponding containers, oil cans, and lubricating positions by different colours for each type of oil used.

Losses of lubricant should be avoided in all circumstances, by sealing off oil leaks and placing suitable receptacles at all points where oil drip occurs during normal operation. In piston compressors, a large portion of the oil used for lubrication can be recovered through oil separators. Lubricant consumption cannot be predetermined accurately, since it depends on compressor design, age, and condition, and on the type of bearings and lubricating system. It can be indicated in various ways, i.e., (1) as a function of the power absorbed by the installation, (2) in terms of the surface area covered by lubrication, or finally (3) as a function of the aspirated quantity of gas. It is necessary to distinguish between the total amount of lubricant supplied (quantity continuously supplied to the compressor) and the net consumption loss (equal to the lubricant supplied minus the amount recuperated). Where grease is used, the free clearance space in the bearings should be filled only to about one-third with bearing grease.

In addition to viscosity, the flash point of the oils should be noted, since this should be in accordance with the maximum temperatures in the compressor. Preference should be given to centralized lubricating systems. It is desirable to incorporate such systems even in older compressors, originally provided with drip-feed lubrication, lubricating nipples, or Stauffer-type grease boxes. For oxygen compressors, with pistons which are sealed only by leather or fibre discs, only softened water or condensate water should be used for lubrication, in order to avoid rapid wear of the cylinders.

Cooling of the compressor during operation is another important factor to be considered. Air cooling is employed only for compressors of fairly small size, and cooling is generally provided by means of a flow of circulating water. In the compressor many different parts are connected to the cooling system. The regulating devices for the cooling water should be designed in such a way that each section of the cooling system may be adjusted individually. The distributing valves or throttling devices at branch points should be preset to fixed positions, so that only the main water valve will need to be actuated for starting or stopping. Provision should be made for the cooling water to be observed as it is discharged. Cooling should be so adjusted that the discharge temperature will not exceed 95 to 105° F, since at higher temperatures the water can easily deposit boiler scale, thereby reducing the cooling action. Excessive cooling can be just as detrimental. An appreciable increase in compressor efficiency is not obtainable by excessive water consumption. Cooling positions at which considerable water consumption is required should be provided with a thermometer in the outflow section to check the temperature. Where fluctuating pressures occur, the flow of cooling water should be adjusted to the lowest pressure. If the water contains impurities, these may tend to cause clogging, particularly in the cooling passages of cylinders and in the casings of rotary compressors, since the flow velocity in these sections is low. It is therefore advisable, in this case, to flush out the cooling-water passages periodically (for instance, once a week) by fully opening the cooling-water valves. Blowing down with compressed air or with nitrogen will clean the passages even more effectively.

The condensate and lubricating oil accumulating in intercoolers and end-stage coolers should be drained off at regular intervals, if automatic draining is not provided. For this purpose, only water drains with a large outflow cross-section (ball-valves) are suitable, since narrow slots are easily clogged by oil emulsions. Where water is recirculated in a recooling system through cooling towers, the progressive deposition of lime should be avoided.

In compressor installations exposed to frost, the entire cooling system should be arranged so that it can be readily drained, and all drain orifices should be left open until resumption of service. Compressors which are operated without constant supervision should be fitted with automatic cut-out devices which operate in case of a temporary failure of cooling water. Any sudden alterations in the quantity of cooling water during operation should be avoided, as they may cause distortion of cylinders or casings and hence possible seizure of pistons or rotors.

Filters in the suction lines reduce wear and hence increase the life of the compressor. Their use is essential in works where a considerable amount of dust is generated. Good dust filters are also of primary importance for dry-running non-lubricated compressors,

which are now being more widely used. In these compressors, the piston and the piston rod are fitted with carbon sealing rings or labyrinths. If the cylinder is not made of stainless material, it is essential to avoid rust formation. The extent of fouling of the filters can be determined by resistance measurements, and appropriate cleaning of filters will ensure that there is no falling-off in the delivery of the compressor.

For the checking of operating conditions, each stage should be provided with a pressure gauge, a safety valve, and a thermometer. The safety valves should be frequently inspected. To simplify supervision, all instruments, including those of the drive unit, should be mounted on a panel. In compressors handling combustible gases, leakage on the suction side may allow air to be drawn in and thus form an explosive mixture. It is therefore advisable to incorporate a pressure-sensitive device which cuts out the compressor when there is a decrease in pressure in the suction line.

The regulating system of compressors adjusts the delivery in accordance with the demand, while maintaining the final pressure as constant as possible. Several types of regulators are employed, i.e., speed, idling-speed and no-load governors, flow controllers, cut-outs, relief valves, and throttle-type regulators. Their functioning requires the fullest attention, since the economical and safe operation of the compressor depends on these devices. If the final pressure is not kept within assigned limits, the regulating device should be examined and the trouble eliminated.

For the normal maintenance of the compressor it is necessary to keep a log-book, with a new printed form or sheet for each day. The principal measured values are recorded regularly, e.g., at hourly intervals. The operating data—time, pressures, temperatures, delivery outputs, oil levels, and total running time—are thus available and can be used to clarify trouble or breakdowns. It is advisable to keep this information over a fairly long period.

Electric motors are generally employed to drive compressors, which may be either directly coupled, gear- or belt-driven. If the direction of rotation of the compressor is not indicated by the maker, it is advisable to mark this direction with an arrow on the machine, to avoid damage due to incorrect direction of rotation after subsequent changing of motors or controls.

Repairs and Overhauls

Even with adequate care, compressor failures cannot be entirely eliminated, and it is important that personnel be trained to report immediately any damage or suspected trouble. Where unusual failures have occurred, it is necessary to ascertain their causes and the means of avoiding or counteracting them in future. The possibility that similar damage may also occur elsewhere should likewise be considered, in order to determine preventive measures. Repair work should be preceded by a detailed investigation of the extent and type of the damage. Before major repairs are undertaken, the results of this study should be recorded in reports with sketches and photographs. A thorough analysis of the trouble before undertaking repairs is a protection against any further damage which might arise if subsidiary or other difficulties are not recognized in time.

The decision regarding the repairs to be carried out also depends on the spare parts and the time available for such work, in view of operating considerations. However, temporary repairs should be avoided as far as possible. Too much emphasis on the question of responsibility while investigating the cause of the damage may make it difficult to clarify. It is only when all the circumstances are appreciated and error on the part of personnel is clearly proved that the required instructions or warnings should be issued, so as to avoid similar occurrences in future. In doing this, improvements or changes in operating procedure should also be considered.

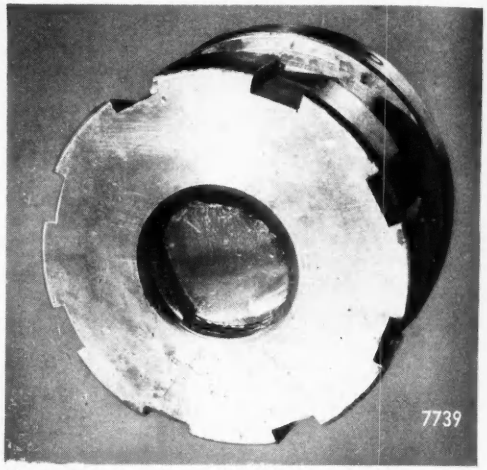

Fig. 1. **Fracture of compressor piston rod in the threaded connection to the cross-head.**

Repairs can be undertaken in the firm's own repair shops to the extent that competent personnel is available. However, it is advisable to call in a specialist from the manufacturers in case of a major repair undertaken for the first time or if the necessary experience is lacking. Before being put back into service after fairly extensive refitting, the compressor should be rotated manually several times, to verify that pistons and rotating parts are free. For extensive repairs of low-power compressors, it is more economical to send the machine to the makers for overhauling, since they possess the special equipment necessary for this work to be carried out rapidly and at a minimum cost. A detailed report should then be requested on the work carried out.

For rapid reconditioning it is necessary to keep stores of all principal spare parts. The costs of keeping these stores are compensated by the operating time saved in avoiding extensive stoppages in production and make it less important to have machines in reserve for such contingencies. For each compressor the suppliers should be required to provide a list of replacement parts, with sectional drawings and reference numbers for the components. In particular, when an order is being made for new compressors, it is not advisable to be too economical as regards spares. The number of parts can be reduced, as indicated by experience after a fairly long period of operation. Replacements should first of all be available for those parts which are subject to considerable wear. All spares received should immediately be checked as regards dimensions, so that they will be found suitable later, when required. A card index should be kept, with a separate card for each compressor. On each card, the number and type of spares received by and handed out from the stores should be noted. This information can serve as a basis for indicating any excessive consumption of spare parts and noting the behaviour of various materials or modified designs. Spares should be stored in a suitable location.

With regard to the subject of overhauls, it is worth mentioning that regular inspection of plant is the best precaution against trouble and failures. General rules cannot be laid down for the time intervals or the extent of the overhauls, but intervals should be determined from operating experience, and an overhaul schedule can then be drawn up.

For piston compressors in continuous operation, inspection should be undertaken about once a year, in order to check bearing clearances, pistons, packings, valves, timing gear, etc. Moreover, in determining

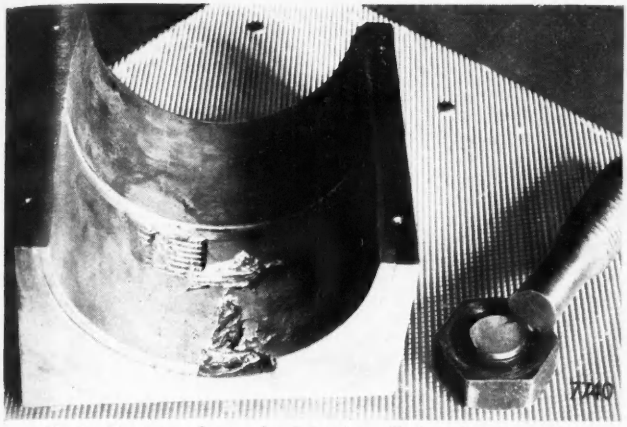

Fig. 2. **Fracture of cross-head bearing-adjustment screw and damaged bearing.**

the intervals between overhauls, the purity of the compressed air or gases delivered should also be taken into account.

For overhauls, as well as for repairs after mechanical trouble, corresponding entries should be made in a log-book, with information on parts showing signs of wear. In this way, the compressor and its operating behaviour can be followed throughout its service life, and valuable experience is obtained. This is a particular advantage when ch nges take place in operating personnel.

During overhauls, all parts exposed to particularly high loads or operating with appreciable rates of wear should be investigated for any signs of weakness, or other defects in materials, verifying that all highly loaded components are still in good condition and that the wear normally expected remains within permissible limits. After dismantling, all parts should first be thoroughly cleaned with well-proven solvents. Pressure vessels and separators which require supervision should be subjected, during the overhaul, to the prescribed pressure tests and also examined internally and externally every four years. Whenever a machine is being cleaned, all pipework and the drive units, together with their ancillary equipment, should be included.

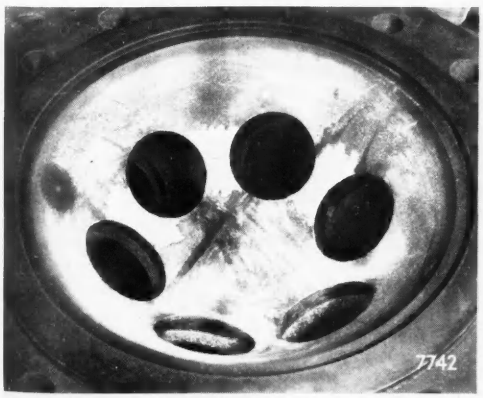

Fig. 3. **Cylinder cover of a refrigeration compressor, showing cracks in three webs.**

In piston compressors, alternating loads caused by the reciprocating motion produce particularly arduous conditions. Knocking sounds may be warnings of excessive bearing play or loose connections at the cross-head, piston, flywheel, or valve seats. In multi-stage compressors, an increase in intermediate pressure indicates leakage in the suction or the delivery valve of the next higher stage. The threaded connection between piston rod and cross-head may fail through high localized stresses caused by notch effects (Fig. 1). Also, the adjustment of the cross-head bearing may be highly stressed and should be examined (Fig. 2). Severe damage may result if core plugs become loose and fall out of the piston. If a plug is slack, its thread, owing to the alternating load, may wear to such an extent that the plug will fly out and lodge between the piston and the cylinder cover. Plugs must therefore be tight and locking devices satisfactory. Furthermore, on cylinder covers with openings for the suction and delivery valves, cracks may occur as a result of unsatisfactory design (Fig. 3). The bolts of the big-end bearings are also highly stressed and should be very carefully examined, as well as their locking devices. The stuffing box can ensure tightness only if the piston rod is round and has the same diameter over the entire length of the stroke. It is necessary, therefore, to check the diameter, since the piston rod wears more rapidly towards its middle section than at the ends. Instead of re-machining an old piston rod, it is preferable to fit a new rod, in order to maintain a standard rod diameter.

Fig. 4. **Damaged valve plates from a piston compressor.**

The increased speeds of modern vertical compressors impose stringent requirements on suction and delivery valves. The valve plates are subjected to impact loads, which depend on the amount of lift. Consequently, when regrinding valve seats, their tolerances should be corrected accordingly. Valve plates should not be made with blunt cutting tools; otherwise, cracks will be generated at the cutting edges, and these may be the origin of a fatigue failure. Valve springs should be adjusted to a suitable load. Excessive spring force results in flutter and rapid destruction of the valve plates, while insufficient spring force causes the valve plate to close late on stroke reversal, with a violent impact due to gas pressure (Fig. 4). The retaining screws of balance weights on the crankshaft are important elements which should be examined for cracks and adequate locking, in order to avoid severe damage. Pumps and pump drives should also be examined in detail. If a shaft fracture occurs in a gear-type pump (Fig. 5) the resulting damage may be very considerable. In one instance, owing to the consequent failure of lubrication, the big-end bearing was destroyed. As a result, the clearance of the crankshaft increased to such

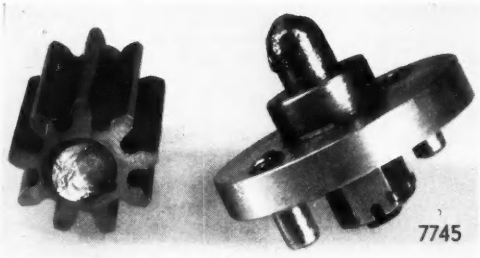

Fig. 5. **Fracture of drive shaft of an oil pump.**

an extent that the piston broke through the cover.

Centrifugal compressors operate with very little wear and have a long service life. In normal overhauls the packing glands, bearings, and gears need careful inspection. Rough running indicates an abnormal condition of some kind and should be remedied without delay. The cause may be situated inside the compressor, but external causes should also be considered, e.g., displacement of the foundations, loose foundation bolts, and changes in alignment. Delivery should not drop below the normal minimum limit.

Rotary compressors also require inspection at annual intervals, to assess the amount of wear. The condition of roller bearings, which are frequently incorporated, should then be noted. Loosening of the inner races, with resulting eccentricity of the rotor, may lead to expensive repairs. Any reboring or regrinding of casings and covers found necessary should preferably be carried out by the manufacturers.

Out-of-Service Maintenance

Long periods out of service can be detrimental to compressor plants. It is therefore recommended that the compressor be run for one-hour periods at suitable intervals. If a short run cannot be carried out, the machine should be rotated manually and lubricated approximately once a month. For a prolonged standstill, after cleaning all parts, including the cooling passages, the compressor can be inhibited with oil or a rust-preventing varnish, and the suction and compression lines should be sealed off.

If a compressor of the dry-running type is to remain inoperative for a fairly short period, it should be run dry for some time before stopping, with the cooling cut off. For longer periods out of service, the valves and piston should be dismantled, and the cylinder and piston should be cleaned, dried, and then hermetically sealed.

SWITZERLAND

The Atomization of Liquids

By H. A. Troesch. (From Thesis No. 2266, *Eidgenössischen Technischen Hochschule, Zurich*, 1954, 14 pages, 6 illustrations.)

(Concluded from August issue)

Droplet Characteristics (*Continued*)

It is reasonable to define the probability of a macro-distribution as the number of micro-distributions which are capable of producing it. This is known as the "thermodynamic probability" or "statistical weight"; it is a very large number, since there is always a vast number of possibilities (micro-distributions) to be considered. It will now be necessary, therefore, to use the methods of classical statistics.

In order to apply the laws of probability calculations, the entire quantity of liquid should be imagined as divided into individual molecules. These may be distributed in any manner, for the time being, in individual "cells." On arriving at each cell the molecules combine and are assumed to form for each cell droplets of a typical size. Thus, the n-th cell will contain droplets only of diameters between Φ_n and $(\Phi_n + d\Phi)$, while the $(n + 1)$-th cell will only have droplets of diameters between Φ_{n+1} and $(\Phi_{n+1} + d\Phi)$. Each small diameter interval is thus situated in its corresponding cell.

The question now arises as to how the cells should be spaced in order to be able to calculate with the same *a-priori* probability for each cell. Should the diameter Φ increase by a constant value $d\Phi$ from cell to cell, or should it be the surface area S with a constant increment dS, or finally the volume V of the droplets with a constant increment dV? It was not possible to reach a definite decision in this regard by theoretical considerations. However, an examination of the measured curves available showed that the best agreement with experiments can be reached if the diameter Φ is increased by a constant value from cell to cell (Fig. 4).

To avoid this restrictive assumption, however, in the following it will be convenient to introduce a "cell-volume" function $\Delta\tau$. The *a-priori* probability of finding a certain molecule in a cell will be regarded as being proportional to $\Delta\tau$. Thus, in general, $\Delta\tau$ will at first be a still unknown function of Φ.

It can now be stipulated that the total surface area of all the liquid droplets generated will have a prescribed value. It is necessary to investigate, therefore, how the atomized volume of liquid, in compliance with these requirements, will be distributed with the greatest probability in the individual cells (i.e., how it will be distributed over the various diameters Φ).

The notation to be used is as follows :—

N = total number of molecules.
v = volume of one molecule.
$V = Nv$ = total volume of liquid.
N_i = number of molecules situated in the i-th cell.
$V_i = N_i v$ = volume of liquid situated in the i-th cell.

There are $N!/(N_1!\,N_2!\,\ldots\,N_i!)$ possible ways of distributing the N molecules in the space of the cells, so that there will be N_1 molecules situated in the 1st cell, N_2 in the 2nd cell, and generally N_i in the i-th cell. The probability of obtaining this distribution is

$$p = N!/(N_1!\,N_2!\ldots N_i!) = N^N/\pi\,(N_i{}^{N_i}) \quad \ldots \quad (19)$$

using Stirling's approximation ($N! \cong N^N/e^N$). It will be easier in the following to consider the logarithm of the probability, i.e.,

$$\log_e p = N \log_e N - \Sigma\,(N_i \log_e N_i) \quad \ldots \quad (20)$$

The distribution which is being sought is that which can be expected with the maximum probability. This means that the function of eq. (20) is required to be an extremum. The auxiliary conditions are :—

(a) Constancy of the total volume : $\Sigma V_i = \text{const.}$ (21a)
(b) Constancy of the total surface area of the droplet mixture during the diffusion process :

$$\Sigma\, s(i)\, V_i = \text{const.} \quad \ldots \quad (21b)$$

where $s(i)$ = cell area per unit volume [m^{-1}], i.e., the surface area occupied by the droplets in the cell when the cell contains a unit volume $V_i = 1$.

It will also be assumed that the energy of the system is constant, i.e., according to Grassmann, that the atomization occurs so rapidly that there is not sufficient time for kinetic or surface energy to be converted into heat. This assumption seems to be verified in practice (see Figs. 3b and 4). Moreover, with the introduction of the density function F_i of the volumes, defined as

$$F_i = V_i/\Delta\tau_i \quad \ldots \quad \ldots \quad (22)$$

the auxiliary equations (21a, b) can be written as $\Sigma\ F_i\ \Delta\tau_i = \text{const.}$ and $\Sigma s(i)\ F_i\ \Delta\tau_i = \text{const.}$, while eq. (20) becomes

$$\log_e p = (V/v)\log_e (V/v) - \Sigma\,[(F_i\,\Delta\tau_i/v) \times \log_e (F_i\,\Delta\tau_i/v)] \ldots \quad (23)$$

Now, the function F_i is to be chosen in such a way that it will make the value of $\log_e p$ a maximum, while taking account of the auxiliary conditions. The usual method for this purpose is to multiply the auxiliary equations by $-\alpha/v$ and $-\beta/v$, and to add these to eq. (23).

Assuming that F_i is the desired function, by varying it slightly at some position, e.g., in the k-th cell, the following variation of eq. (23) is obtained :—

$$-\delta\log_e p = \Sigma[\delta F_i\,(\Delta\tau_i/v) \times \log_e (F_i\,\Delta\tau_i/v)] + \Sigma\,\delta F_i\,(\Delta\tau_i/v + (\alpha/v)\,\Sigma\,\delta F_i\,\Delta\tau_i + \beta/v\,\Sigma\,s(i)\,\delta F_i\,\Delta\tau_i \quad \ldots \quad \ldots \quad (24)$$

As F_i is the minimum function, the variation according to eq. (24) must vanish. Let F_i be varied only in the k-th cell ; then, all δF-terms excepting δF_k will vanish, and consequently

$$\delta F_k\,\Delta\tau_k\,\{(1/v) \times \log_e (F_k\,\Delta\tau_k/v) + (1/v) + (\alpha/v) + (\beta/v)\,s\,(k)\} = 0 \ \ldots \quad (25)$$

Reverting to the subscript "i," the condition that the expressions in the chain brackets must vanish is obtained, i.e.,

$$\log_e (F_i\,\Delta\tau_i/v) + 1 + \alpha + \beta\,s(i) = 0.$$

Hence, $F_i\,\Delta\tau_i/v = \exp\{-(1 + \alpha + \beta s(i))\} \quad \ldots \quad (26)$

With the abbreviation $B = (v/\Delta\tau_i)\ \exp\{-(1 + \alpha)\}$, eq. (26) becomes

$$F_i = V_i/\Delta\tau_i = B\exp(-\beta s(i)). \quad \ldots \quad (27)$$

This is the volume distribution function F_i which was to be found. It shows how the molecules expelled into the diffuser section are distributed among the cells $\Delta\tau$.

Now, it is required that the N_i molecules in the i-th cell should form n_i droplets of diameter Φ_i. This means, using eq. (27), that

$V_i = n_i\,(\pi/6)\,\Phi_i{}^3$, and $F_i = (n_i/\Delta\tau_i) \times (\pi/6)\Phi_i{}^3$ (28a, b)

Similarly, a droplet-number frequency function can be introduced, so that

$$f_i = n_i/\Delta\tau_i \quad \ldots \quad \ldots \quad (29)$$

Then, $F_i = f_i\ (\pi/6)\Phi_i{}^3$. With $B' = 6B/\pi$, this expression for F_i can be used in eq. (27) and gives

$$f_i = (B'/\Phi^3)\exp\{-\beta s(i)\} \quad \text{or}$$

$$n_i = (B'\Delta\tau_i/\Phi^3)\exp\{-\beta s(i)\} \quad \ldots \quad (30)$$

The total number of droplets, of which the diameter must lie between zero and Φ_{max}, is, when a fine subdivision is used,

$$n_o = B'\int_0^{\Phi_{max}} e^{-\beta s(i)} \times \frac{d\tau_i}{\Phi^3} \quad \ldots \quad \ldots \quad (31)$$

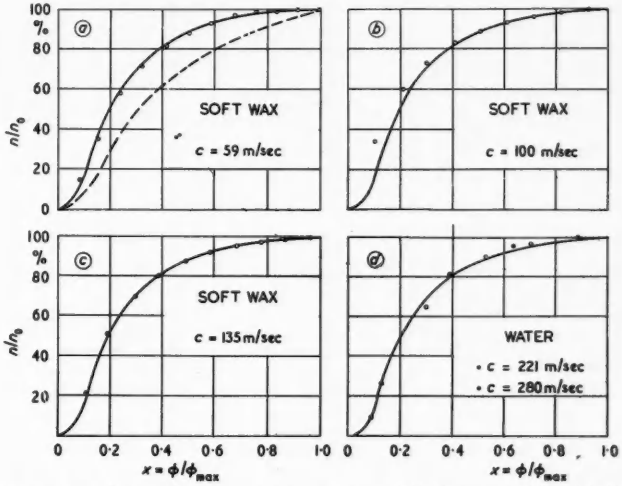

Fig. 4. **Droplet-number summation curves, calculated from eqs. (18) and (38), with $\lambda = 0{\cdot}35$, in dimensionless representation.**

Full lines $\Delta\tau = \Delta\Phi$; dotted line $\Delta\tau = \Phi\,\Delta\Phi$.

(a), (b), (c) Compressed-air atomizers in which the liquid is injected in a plane perpendicular to the direction of air velocity.

(d) Compressed-air atomizer in which the liquid is injected at an angle relative to the velocity of the atomizing air. Diameter of air nozzle = 54 mm ; diameter of liquid nozzle = 1·5 mm.

Relating eq. (30) to unity,

$$\mathrm{d}\,n/n_o = (e^{-\beta s(i)}\,\mathrm{d}\tau_i/\Phi^3)\Big/\int_0^{\Phi_{max}} e^{-\beta s(i)}\,\mathrm{d}\tau_i/\Phi^3 \ldots \quad (32)$$

The procedure for calculating the surface area $s(i)$ of the cell, i.e., the area occupied within the cell by a unit volume, is as follows :—The total volume in the i-th cell is $V_i = n_i\,(\pi/6)/\Phi_i{}^3$; this volume, by virtue of eq. (21b), has a surface area

$$S_i = n_i\pi\Phi_i{}^2 \ ; \quad \text{hence} \quad s(i) = 6/\Phi_i \quad \ldots \quad \ldots \quad (33)$$

The cell-volume function has been defined as

$$\Delta\tau_i = F\,(\Phi)$$

On the basis of the test results, let

$$\Delta\tau_i = F\,(\Phi) = \Delta\Phi \quad \ldots \quad \ldots \quad (34)$$

which is the diameter increment itself (Fig. 4a). Then, introducing this value and $s(i) = 6/\Phi_i$ in eq. (32),

$$\mathrm{d}n/n_o = (e^{-6\beta/\Phi}/\Phi^3)\,\mathrm{d}\Phi\Big/\int_0^{\Phi_{max}} (e^{-6\beta/\Phi}/\Phi^3)\,d\Phi \ \ldots \quad (35)$$

This gives the droplet-number frequency curve as a function of the droplet diameter. Putting $x = \Phi/\Phi_{max}$, $\lambda = 6\,\beta/\Phi_{max}$ (with Φ_{max} from eq. (18)) and relating to unity

$$\frac{\mathrm{d}n/n_o}{\mathrm{d}x} = \frac{e^{-\lambda/x}/x^3}{\int_0^1 e^{-\lambda/x}\,\mathrm{d}x/x^3} \quad \text{(see Fig. 5)} \quad \ldots \quad (36)$$

This is the function related to unity of the droplet-number frequencies. It is derived from a rigorous theory related to experimental considerations and contains only one freely selectable parameter, λ. It is required in this connection that Φ_{max} should be calculated from eq. (18). There is no requirement regarding the constancy of the total number of droplets, which would have brought in another free parameter. It has been pointed out by Grassmann that $1/\lambda$ plays in this theory a role similar to that of the temperature T in the statistical theory of gases.

It should also be noted that, as expected from the theory, for compressed-air atomizers in which liquid is injected in a plane perpendicular to the direction of air

velocity, λ has a constant value, which has been confirmed by tests. For the extremum positions of the frequency function (36), the values of abscissae corresponding to horizontal tangents are as follows :—

(a) $x = 0$; and
(b) $x_{extr} = \lambda/3$ ... ... (37)

OTHER CHARACTERISTICS

Besides the frequency curve of the droplet numbers, its summation curve, i.e., the integral of the function in eq. (36) plotted against droplet diameter is also used. This is particularly suitable for evaluating test results. The difference in ordinates corresponding to two diameters represents the probability of occurrence of droplets in the diameter interval considered.

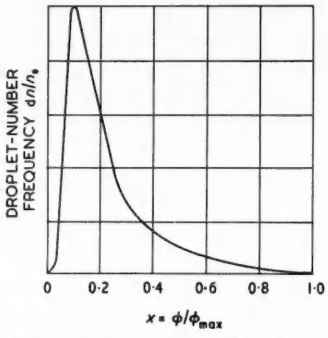

Fig. 5. **Droplet-number frequency curve, according to eq. (36), with $\lambda = 0{\cdot}35$, in dimensionless representation.**

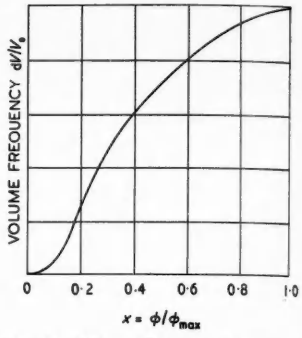

Fig. 6. **Volume-frequency curve, according to eq. (41), with $\lambda = 0{\cdot}35$, in dimensionless representation.**

Integrating the function (36) between the limits $x = 0$ and $x =$ variable, $\alpha = \lambda/x$ and $x = \Phi/\Phi_{max}$

$$n/n_o = \frac{(1 + \alpha)\, e^{-\alpha}}{(1 + \lambda)\, e^{-\lambda}} \quad \text{(Fig. 4)} \qquad \ldots \quad (38)$$

which is valid for the range $0 \leq x \leq 1$.

Moreover, the frequency curves of the surface area and the volume of the droplet mixture are also of some interest in relation to the average droplet diameter. Let S_o denote the total surface area ; then, from eq. (36), the surface-area frequency function is

$$y = \frac{dS/S_o}{dx} = \left(\frac{1}{x} e^{-\lambda/x}\right) \Big/ \int_0^1 e^{-\lambda/x}\, dx/x \qquad \ldots \quad (39)$$

where $dS = \pi \Phi^2\, dn$. It can easily be verified that this function has a horizontal tangent at the origin ($x = 0$) and a maximum at $x = \lambda$.

The integration of the frequency curve of eq. (39) gives the summation curve

$$S/S_o = \text{Ei}\,(-\alpha)/\text{Ei}\,(-\lambda), \text{ with } \alpha = \lambda/x \qquad \ldots \quad (40)$$

for the interval $\lambda \leq \alpha \leq \infty$. In this expression, the usual notation

$$\text{Ei}\,(-\alpha) = \int_{\infty}^{\alpha} \frac{e^{-u}}{u}\, du$$

has been employed.

Putting $dV = (\pi/6)\, \Phi^3\, dn$, then, with the aid of eq. (36) the volume frequency curve is obtained as

$$P = \frac{dV/V_o}{dx} = e^{-\lambda/x} \Big/ \int_0^1 e^{-\lambda x}\, dx \qquad \ldots \quad (41)$$

which has a horizontal tangent at the origin. However, it does not have a relative maximum, as in Fig. 5, but an absolute maximum at the point $x = 1$ (Fig. 6). By graphical integration, it can be shown, not only for this special case, but as a general rule, that for every volume-frequency curve, the abscissa of the maximum is at the value Φ_{max} of the largest droplet diameter, which is calculable from eq. (18), regardless of the type of atomizer employed ($x = 1$ is independent of $1/\lambda$). The integration of eq. (41) gives the volume-summation curve

$$V/V_o = [\alpha^{-1}\, e^{-\alpha} + \text{Ei}\,(-\alpha)]/[\lambda^{-1}\, e^{-\lambda} + \text{Ei}\,(-\lambda)] \qquad (42)$$

with $\lambda \leq \alpha \leq \infty$.

THE MEAN DROPLET DIAMETER

In published literature, the mean droplet diameter D_m of a mixture is usually defined in such a way that the equivalent mixture (consisting of droplets of uniform size) will have the same ratio of volume to surface area as the original mixture. Assuming that the same molecular volume v is used for either mixture, the surface energy per unit volume or per molecule will then be the same in both cases. On the basis of this definition, the mean droplet diameter is obtained as

$$D_m = \int_0^{\Phi_{max}} \Phi^3 dn \Big/ \int_0^{\Phi_{max}} \Phi^2 dn = \Phi_{max} \times \int_0^1 x^3 dn \Big/ \int_0^1 x^2 dn \quad (43)$$

Taking the value for dn from eq. (36) and integrating,

$$D_m = \Phi_{max} \times \lambda \times \left[\frac{-e^{-\lambda}}{\lambda \times \text{Ei}\,(-\lambda)} - 1\right] \ldots \quad (44)$$

The stability criterion of eq. (18) was verified in tests made by the author and other investigators over the range of Reynolds numbers Re_{fl} (related to the droplets) extending from 20 to 27,000.

It allows the maximum droplet size to be predicted for rotating pressure atomizers, normal compressed-air atomizers, and probably also for other types, provided that no subsequent recombination of droplets occurs outside the actual atomizing chamber. For the only parameter λ requiring experimental determination, it was found that test results indicate a value of $\lambda = 0{\cdot}35$, which is a constant for normal compressed-air atomizers.

With this value of λ, eq. (36) can be employed to obtain the frequency curves for compressed-air atomizers. The predicted values are in good agreement with experimental results. This equation, with only one empirical parameter, which is a constant for certain atomizer types, is probably the only equation so far published which can be used to predict the distribution curves purely from calculations.

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British Industrial Developments

Single-Shaft Gas Turbine

The Napier "Oryx" turbo-gas generator, announced by D. Napier & Son Ltd., of Acton, London, W.3, is a single-shaft gas turbine designed primarily for operation in helicopters in which the rotor is propelled by jet reaction at the rotor-blade tips. In this method of propulsion, the absence of a reduction gear, driving shaft, and geared rotor head enables a considerable saving in installed weight to be made, improves mechanical reliability, and reduces maintenance costs.

The engine comprises a twelve-stage axial-flow main compressor, five combustion chambers, a two-stage reaction turbine, and a four-stage axial-flow auxiliary compressor. The air from the auxiliary compressor enters a volute in the collector, into which the turbine also exhausts, through a separate volute. The air and gas are delivered from a flange on the collector to a two-position non-throttling valve, which diverts the mixture either to the free exhaust or to the rotor head, as required. Control of the engine is effected through an interconnected fuel-metering unit operated by a single lever, automatic compensation being provided for changes in ambient pressure and temperature conditions. It also includes an overspeed governor and a fixed-datum turbine-inlet temperature control. Fuel is supplied by a Lucas fixed-stroke plunger pump. An inlet guide-vane control, responsive to engine speed, is also fitted. Control of the starting butterfly valve and the two-position non-throttling valve is manual. In the case of a twin-engine installation, in which both engines deliver to a common duct, the manual control of the two-position valve may be overridden by a speed-sensing unit in the case where the engines are not running at synchronized speed.

Dry-sump lubrication is used and the necessary oil cooler and oil tank are installational items. The rotary positive-displacement type of pressure pump delivers oil at 150 psi, which is restricted to maintain an engine oil pressure of 80 psi and a pressure of 135 psi in the non-throttling valve servo-mechanism reservoir. The oil filter is contained within the pump housing. Each of the pumps comprising the three-bank scavenge pump is divided into two, so that independent scavenging is obtained for each of the six main engine bearings.

The engine performance and handling characteristics benefit from the typical Napier compressor characteristics, in which the optimum efficiencies are obtained well removed from surge. This feature permits the operating line to be set at an ample margin from surge, thus permitting good handling qualities, without loss of efficiency in normal operation. The engine, which has achieved its design performance and has completed 1350 hours of test-bed running, will shortly be installed in the Hunting-Percival P.74 helicopter. By the end of 1955 a type test to the standard rating of 750 gas horse power will be attempted and preliminary development at 825 ghp started. It is anticipated that the engine will be developed to 900 ghp by the end of 1956.

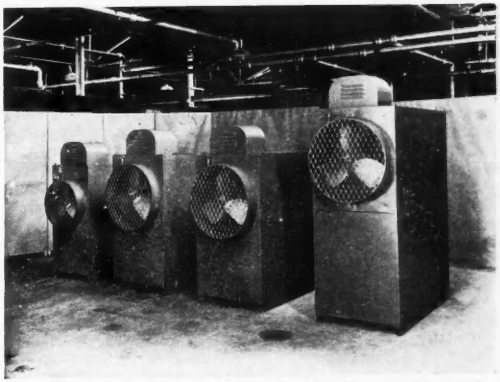
Further Developments in Nimonic Alloys

Closely following on their recent announcement of new production developments which made it possible to produce cooled blade sections in the Nimonic alloys, Henry Wiggin & Co. Ltd, of London, S.W.1, have now released preliminary information on a new alloy in the series, known as Nimonic 100, which, like the previous alloys, was developed in the research laboratories of The Mond Nickel Company Limited.

Following its successful testing in the laboratory, intensive production development had to be undertaken in order to make the new alloy available in production quantities. Quantities of Nimonic 100, which has very high resistance to creep but which may be used at temperatures some 30°C higher than those permissible for previous alloys in the Nimonic series, have now been supplied to several gas-turbine builders for complete evaluation in actual engines.

Single-Flow Water Coolers

An agreement has been entered into between Heenan & Froude Ltd., of Worcester, and the Marley Company, of Kansas, for the production of Heenan-Marley water coolers. Under this agreement the British company, as exclusive licensees, will manufacture coolers for practically all countries outside North and South America. They will be of Marley design, with slight modifications for British requirements. The Heenan "P"-type of forced-draught cooler will continue to be manufactured in cases where it is the most suitable type for the duty. The Marley Company holds a "cross license" to build Heenan coolers.



The first models to be marketed by Heenan & Froude will be the single-flow "Aquatowers," which will be followed by larger types. The "Aquatower" range of 11 sizes (four of which are illustrated) covers low-temperature cooling (refrigeration plants, air compressors, etc.) from 200 to 4800 gallons per hour, and

high-temperature cooling (diesel generator sets, etc.) from 600 to 13,500 gallons per hour. The single-flow "Aquatower," which operates on the induced-draught cross-flow principle, is designed to reduce running costs for users of many different types of equipment, ranging from refrigeration and air-conditioning plant to plastic-moulding presses and batteries of spot-welding machines. Among the advantages of these coolers are their low fan power, resulting in reduced electricity costs, and their low height, making them particularly easy to install in confined spaces.

Heenan-Marley coolers have all-metal casings, finished internally with a special anti-corrosive compound. Fan blades are also protected against corrosion. Oil cups are located outside the cooler casing for accessibility. Water is distributed over the cooling elements by an open-top gravity-flow basin, from which the water overflows to a distribution deck. No nozzles are used, with the result that clogging is eliminated and pumping head is minimized. The design ensures even distribution over the cooling surfaces at all normal rates of flow. The cooling surfaces of timber "filling" ear simple in design, and the timber is treated with a preservative which ensures a long working life.

Routine Metallographic Inspection of Heat-Treated Forgings

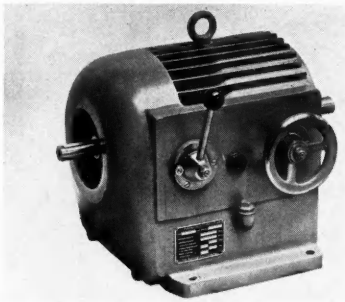
Following development work in the Metallurgy Section of the Guest Keen & Nettlefolds Group Research Laboratory, a chemical method for brightening and polishing plain carbon steels, originally invented at the Armament Research Establishment, Woolwich, has been adopted for routine inspection of heat-treated forgings by Messrs. Garringtons, Ltd.

The component is immersed in the solution for 5 to 30 min; in the case of bulky components a wall of plasticine is put on the surface to contain the solution. Since no mechanical preparation is necessary, the surface of the component can be inspected, so that the laborious cutting out of specimens and hand-polishing of the surface is avoided. Moreover, the component used for examination is not damaged in any way. As a result of these developments it has become possible to use microscopic examination for the routine control of heat treatment and to obtain a much more sensitive indication of the quality of the product. Where micro-examination was used in the past, the use of the new technique has led to a considerable increase in the number of inspected components from each heat-treated batch, so that control has become more reliable, reflecting favourably on the quality of the product.

Variable-Speed Hydraulic Drive

Churchill-Sturm Ltd., of London S.E.11, a new subsidiary of Charles Churchill & Co. Ltd., of Birmingham, has acquired a licence to manufacture and sell the Sturm variable-speed hydraulic drive in Great Britain and throughout the British Commonwealth. The unit, originally developed in Germany, will be marketed under the name of the Churchill-Sturm Hydraulic Drive. It has an unusually wide range of speeds, combined with infinitely-variable speed regulation, constant torque up to about one fifth maximum speed, and constant horse-power throughout the remainder of the range. The unit is reversible, the full range of speed and power being available with either direction of rotation. Frictional losses are reduced to a minimum, resulting in an unusually high efficiency which is virtually constant under all normal operating conditions.

The device consists of an oil pump driven by a constant-speed electric motor or other prime mover. The oil pump drives an oil motor connected to the output shaft. Both pump and motor are enclosed in a common casing, which serves as an oil reservoir; they are similar in construction, comprising a rotor fitted with sliding vanes revolving inside a housing which is adjustable transversely inside the casing, so that the eccentricity of the housing relative to the rotor can be varied, as required. Any desired speed within the range can be obtained merely by altering the positions of the pump and motor housings.



The Churchill-Sturm hydraulic drive is built in a number of sizes, ranging from 1·25 to 32 hp. It can be supplied in various forms to suit the particular machine which it is to drive, while different types of control gear are available, including remote and automatic control. In general, the unit can be adapted to suit the specific conditions of each application and it is ideal for machinery requiring a reversible, infinitely-variable speed drive which is compact, reliable, and efficient.

100-Watt Vibrator Unit

In much commercial electronic and communication equipment designed for mobile operation, it is undesirable to employ motor-generators to produce the necessary a.c. supplies from d.c. inputs. Vibrators are the usual answer to the problem but, where medium-power requirements have to be met, ordinary vibrators are inadequate. A 100-W, heavy-duty vibrator, designed originally for Services use but which is now commercially available, has been produced by The Plessey Company Limited, of Ilford. It can be used in a power pack to give a variety of a.c. output voltages for supplying bias circuits, valve heaters requiring isolation, E.H.T. supplies, etc.

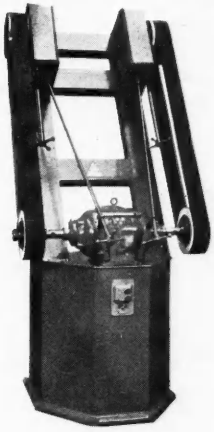
The heavy-duty vibrator has a number of advantages over the rotary transformer, including a reduction in weight, space, and noise, an improved circuit flexibility, and higher efficiency. A power pack incorporating the vibrator has an overall efficiency of 55% to 65%, compared with an average of 40% from a rotary transformer. The Plessey vibrator is a robust unit, made to withstand the temperatures, humidities, vibration, and shocks to which Services equipment is liable. It is hermetically sealed in a robust aluminium case of such wall thickness that mechanical noise is kept to a very low level. Its performance and size ($4\frac{1}{4}$ in. high $\times$ $2\frac{1}{4}$ in. diameter) should make it useful in a wide range of applications, both in Service and commercial electronic and communications fields.

The vibrator is of the synchronous type, working at a frequency of 110 cps nominal, having a split reed and a separate drive, taking a maximum of 5 W driving power. The platinum-iridium-tipped drive-contact screw connects to a platinum-iridium contact spun onto the drive-contact spring, made from high-quality spring steel. The power contacts are manufactured from close-grain swaged tungsten. It employs twin reeds and, to ensure uniformity of material, the reeds are manufactured in one piece, connected together by a small web which is removed after the vibratory system is assembled. Ground ceramic spacers are used throughout, to ensure high mechanical and electrical stability during the life of the vibrator, and all materials used in the construction are carefully chosen so that no injurious gases are produced over the entire working temperature range.

New Materials, Processes, and Equipment

UPRIGHT SELF-CONTAINED BACKSTAND

The latest addition to the range of abrasive-band machines manufactured by the R. J. H. Tool & Equipment Co. Ltd., of Heckmondwike, is a double-ended, upright, self-contained model, powered by a 4-hp totally enclosed motor and incorporating " Major " backstand idler units.



The new machine, designated the R.J.H. " Giraffe," is designed to use standard 11 ft 4 in. × 4 in. abrasive belts, and can be supplied with the appropriate motor and face-contact wheels to give a band speed of 5500 fpm for heavy-duty grinding and fettling of rough castings, or 7500 fpm for lighter-duty grinding or polishing. Free band strapping may also be effected above the contact wheel. The pedestal is cut away in the front, to permit ample working clearance around the sides and below the contact wheels. The overall height is 7 ft 9 in., and both tension and tracking handles are arranged within easy reach of the operator, thereby permitting rapid belt changing. The floor space required is only 2 ft 6 in. square.

The machine is strongly constructed of fabricated steel and has balanced pulleys mounted on sealed ball-bearing spindles, to give rigid, vibration-free working conditions. A push-button starter is incorporated in the front of the pedestal.

BATTERY WITH MOISTURE-PROOF DRY-CHARGE PLATES

While dry-charged batteries are, of course, well known, such batteries ordinarily suffer loss of power during storage. In normal temperatures the conventional dry-charge plate is attacked by the moisture in the air, resulting in a gradual loss of charge. However, the new " Power Seal " plates incorporated into the Oldham " Major " battery by Oldham & Son Ltd., of Denton, Manchester, eliminate this drawback completely, inasmuch as their special treatment renders them absolutely impervious to moisture. As a result, the initial factory dry charge is positively sealed in until the battery is required for service; indeed, even after prolonged storage, the battery will remain "fresh" and fully charged.

Another important advantage of the new plates is the speed with which the battery can be brought into use. Despite the fact that these plates are impervious to moisture, they are, nevertheless, immediately affected by sulphuric acid, so much so that, on being filled with electrolyte, full power, without supplementary charging, is released almost instantly by the battery.

Apart from the " Power Seal " plates, the new Oldham " Major " battery retains its previous features, including the use of moisture-free " Fibrak " separators (an exclusive Oldham development) and extra-rigid " X-Metal " alloy grids.

AUTOMATIC BRINELL-HARDNESS TESTER

A new Brinell-hardness tester, designed for automatic operation, has been developed by Steel City Testing Machine, Inc., of Detroit. In this new instrument, designated " Colour-Glance ", three coloured lights signal the relative Brinell hardness of the testpiece, in addition to making all decisions of acceptability or rejection. Furthermore, when combined with automatic means of handling parts on a production-line basis, the new unit can be made to sort the work after testing. The three signal lights are arranged so that a yellow signal indicates " too hard ", green " within range " and red " too soft ". Limits are easily adjustable to suit the requirements of each job. During the test cycle, one of these lights flashes on, indicating the hardness category of the part under test.

Basically, the new machine is similar to a standard direct-reading type of Brinell-hardness tester, with the exception that a dial indicator with adjustable electric contacts replaces the standard indicator and is connected to a specially designed control panel. No electronic devices are employed, thereby reducing the expense of maintenance. The machine itself is hydraulically operated.

The test cycle is as follows :—The operator places the part to be tested on the anvil, which has been previously adjusted so that the test surface will be within approximately 0·5 in. of the Brinell ball penetrator. A knee switch on the front of the machine is then momentarily depressed, starting the test cycle. The machine automatically applies the Brinell load, indicates the relative hardness of the test specimen by illuminating

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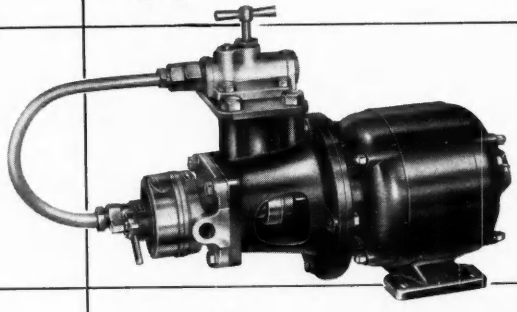

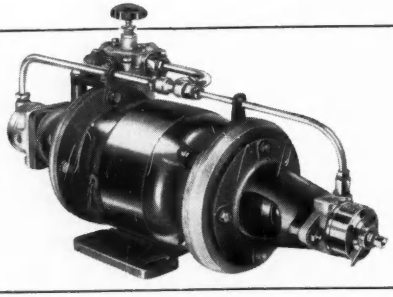

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one of the signal lights, and then releases the load, retracting the penetrator. The operator removes the part and the machine is ready for the next test.

To set up for completely automatic operation, the same circuits which operate the lights can be used to activate solenoid valves, switches, or other electrical equipment for physically sorting the parts into the three categories. Special means can also be provided for starting the machine cycle when the part to be tested is properly located on the anvil.

PRECISION ROLLER-LAPPING MACHINE

Claimed to produce finishes as fine as 2 r.m.s. or less, a new precision roller-lapping machine for metal and glass, or plastic plugs, rods, or pins, from $\frac{1}{8}$ to 6 in. in diameter, has been developed by the Spitfire Tool Company, of Chicago, Illinois.

The equipment consists essentially of two precision-ground cast-iron rollers, with shafts extending on both sides and revolving in adjustable bearings. The rollers are parallel, 12 in. in length, one being 3 in. and the other 6 in. in diameter. The large roller is constructed with dual internal air chambers, vented by four openings for each chamber. This, plus the large mass of the rollers, keeps down the temperature of the work, thus making it unnecessary for "cooling off" periods. Both rollers, by means of a worm-gear drive, rotate in the same direction, away from the operator, and at the same speed. A four-step V-belt pulley permits speed variations. The rollers can be quickly adjusted or moved apart to accommodate workpieces of different sizes. The machine has a well-designed, heavy steel base, 38 in. in height, and occupies a floor space of only $22\frac{3}{4} \times 31$ in. No chucks or rings whatsoever are used. Work may be removed quickly and easily at any time for checking and measurement.

In use, the operator spreads abrasive compound evenly over the entire surfaces of both rollers. The motor is started and the piece to be lapped is placed between the rollers. A simple notched fibre stick is employed for applying pressure to the workpiece. This stick is moved slowly and uniformly from side to side across the piece. The friction of the rollers on the piece causes it to revolve, and the differential in surface speed of the rollers causes the lapping action on the piece. To lap a small amount off any particular section of the part, the fibre holder is held longer on that section. Parts with shoulders larger than the diameter to be lapped may be lapped by allowing the shoulder to hang over the end of the rollers.

BELLOWS-SEALED RELIEF VALVE

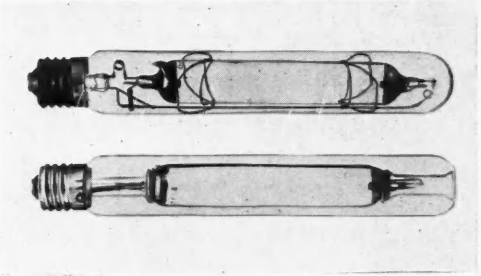
The new "Protecto-Seal" relief valve produced by the Crosby Valve & Engineering Co. Ltd., of Wembley, Middlesex, has been designed primarily to operate against varying downstream or back pressures without any effect on the lifting pressure. This has been achieved by sealing the body of the relief valve from the bonnet or spring case by means of a stainless-steel bellows. As the effective area of the bellows is exactly the same as the area of the nozzle and disc seat, any back pressures on the downstream side of the valve are completely balanced.

Rather than attempt to produce a bellows capable of withstanding normal discharge conditions and yet possessing sufficient flexibility to permit the valve to operate normally, the policy adopted has been that of protecting the bellows from discharge conditions. The exclusive feature of this valve is the bellows shield, which completely surrounds the bellows, the distance between the open-ended bottom of this shield and the disc being such that, when the valve lifts, the top of the disc meets the bottom of the shield. As a result, the bellows is totally enclosed and is completely protected from downstream discharge conditions. In addition, this bellows seal serves the purpose of completely sealing off the fluid from the guide and spring, thereby preventing any possibility of escape to atmosphere.

MERCURY-VAPOUR DISCHARGE LAMPS

Incorporating several original features, the latest mercury-vapour discharge lamps manufactured by Crompton Parkinson Ltd., of London, W.C.2, yield a higher standard of maintained efficiency and possess markedly increased mechanical strength.

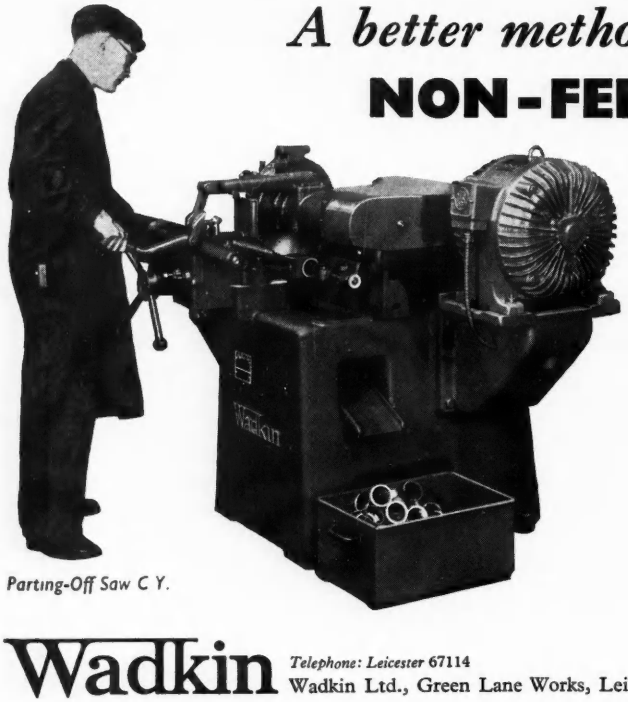
Visibly evident is the exclusive and simple method employed for mounting the inner glass tube (which contains the mercury vapour and electrodes) within the outer glass envelope. This is normally accomplished with a somewhat complex and vulnerable arrangement of springs and clips, whereas in the new Crompton design the inner tube is securely held between two sturdily constructed stems, integral with the outer glass envelope. Asbestos pads located between the inner tube and the stems provide both a cushioning effect and an allowance for expansion due to heat. This neat arrangement gives a convincing appearance of higher resistance to usage and transit shocks than systems employing springs or clips, and, moreover, it is claimed that there is no bulb discoloration caused by overheated wire-work in contact with glass; depreciation in light output



throughout life is therefore substantially reduced. It has been shown, in fact, that the new lamps retain their original internal cleanliness after 4000 hours use. The avoidance of contact between hot wire-work and glass also has the advantage of eliminating glass fracture at local hot spots when the lamps are on and subjected to external cold air currents.

The illustration shows (bottom) the new lamp, which is available in 250 and 400 W sizes, and clearly demonstrates its improved appearance, compared with an older type of lamp (top).

A better method of cutting
NON-FERROUS BARS



Parting-Off Saw C Y.

This Wadkin C.Y. with its easy downward cutting action; its combined single lever clamping and sawing motion; its capstan-wheel operated feed and its chute in the main frame provides a faster and better method of repetition sawing off. It will deal with bars up to 4″ × 2½″ or 3″ round. The work is clamped on both sides of the saw, ensuring clean cutting and even after the cut has been completed it is still held firmly until the saw is raised clear. Components up to 9″ long fall through the chute but if required the machine can be arranged with extended table for cutting off up to 3′ 6″ long.

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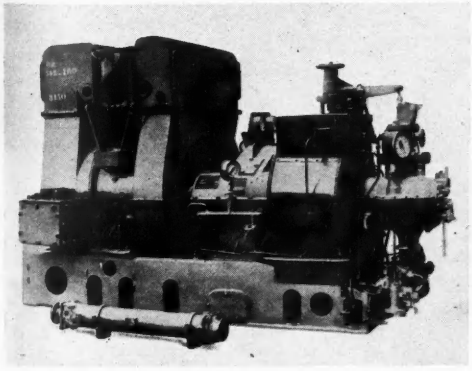
ENGINEERING, MARINE & WELDING EXHIBITION

& THE FOUNDRY TRADES' EXHIBITION

Our August issue contained a preview of some of the interesting products exhibited at Olympia, London. This month a further selection of exhibits is presented.

The exhibits by **The General Electric Co. Ltd.,** of London, were selected to represent important aspects of the Company's comprehensive activities in marine electrification, and ranged from power generation to the smallest installation accessories.

One of the most interesting exhibits was a 325-kW turbo-generator for ships' auxiliary supplies (illustrated). This set, one of twenty being supplied for tankers under construction by the Furness Shipbuilding Co. Ltd. for London Overseas Freighters, is driven by a Fraser & Chalmers 10,000-rpm, high-pressure, multi-stage impulse turbine operating at steam conditions of 425 psig, 725°F total temperature, and a vacuum of 28·5 in. Hg. The turbine is coupled through double-helical reduction gears to a G.E.C. open-canopy, protected-type, compound marine generator wound for 220 V d.c., and designed to develop 325 kW at 1100 rpm. Both turbine and generator are mounted on a common bedplate, which incorporates the oil tank, and the set is arranged to exhaust into the main condenser.



Other exhibits included examples of G.E.C. air-break cubicle switchgear for ships with 440 V, 3-phase, 60 cps, a.c. supplies. A section of a main switchboard showed the alternator synchronizing panels, while part of a typical group-starter board included the starters for steering-gear motors. Separate a.c. direct-to-line and d.c. starters were also shown. The construction of the cubicles for this range of switchgear is such that no supporting framework is necessary, and the unit parts are so designed that cubicles up to 6 ft 6 in. high can be assembled in standard widths from 1 ft 6 in. to 3 ft 6 in. and can be installed individually or joined together to form one switchboard. They will accommodate manually or electrically operated circuit-breakers, fused switches, contactors, isolators, and a full range of instruments. The switchgear is mounted on insulating panels, which in turn are carried on an internal skeleton frame. All parts which might require attention are accessible from the front, but interlocks ensure that they are isolated before the front door can be opened.

A selection of a.c. and d.c. screen-protected, drip-proof motors of horizontal and vertical spindle types included a 440 V, 3-phase turning-gear motor with journal bearings. All machines are insulated to withstand engine-room and tropical conditions.

A new model of the double-oven range for the galleys of medium-size cargo vessels, in which the number of hot plates has been increased from three to four, was also shown. Total loading of the ovens and hot plates is 20 kW. The internal dimensions of the ovens are 21 × 17 × 22 in., while the hot plates, which have simmering facilities, measure 8 × 12 in.

The display arranged by **John I. Thornycroft & Co., Limited,** of London, S.W.1, comprised a selection of their numerous and varied productions of interest to ship and boat owners and to engineers in their many spheres.

An especially interesting exhibit was the new Thornycroft type RJD/2 unit, exhibited for the first time. This engine (illustrated), of 12½-16 hp, is the higher-powered successor of the well-known "Handybilly" DB/2 petrol/paraffin engine, as a direct replacement for which the new unit has been designed, so much so that the width and length of both engines are identical and the new unit can be mounted on existing bearers. A point of interest to ship owners is that the standard engine is acceptable for passenger-carrying launches and ships' lifeboats built to Ministry of Transport requirements. To demonstrate its suitability for this purpose, an engine was shown installed in

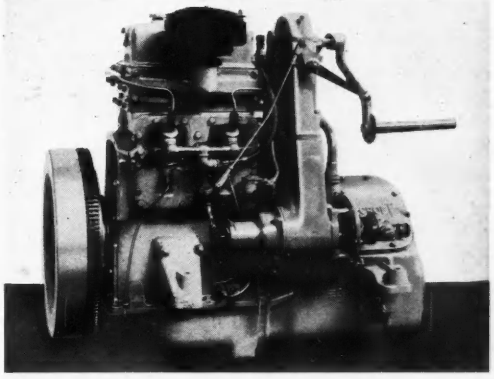


Photo by permission c/ Elkington & Co. Ltd.

. . . Power for Purification at Elkington & Co. Limited's works is provided by 18 Davenset Glass Bowl Mercury Arc Rectifiers with separate oil filled Transformers controlled by Automatic Stepless Voltage Regulators.

This installation is used for the electrolytic refining of copper from scrap.

This is typical of important installations where continued processing is essential.

RECTIFIER INSTALLATIONS

DAVENSET

PARTRIDGE, WILSON & CO. LTD. Davenset Electrical Works, Leicester

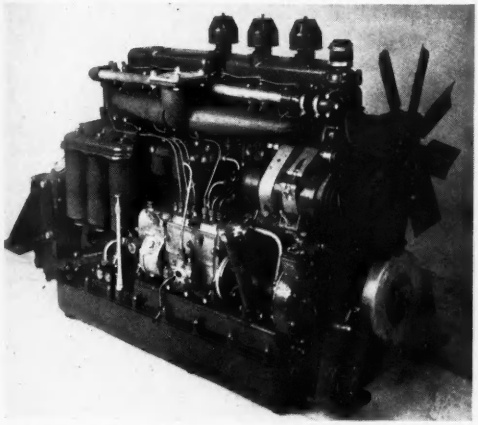
a 24-ft aluminium-alloy ships' lifeboat, with a similar engine alongside, to facilitate close inspection.

Thornycroft marine diesel engines of other powers include the type RTR/4 4-cylinder model of 30 bhp, suitable for a wide range of commercial and pleasure craft, and the type RZ36 6-cylinder 125-bhp engine, intended for faster classes of craft.

Other exhibits included the new RJD/2 engine as the prime mover of a distilling plant designed essentially for the production of drinking water from sea water, and the latest type of Thornycroft oil-fuel burner, five of these burners being fitted to a furnace front, with a separate demonstration mounting, enabling the operation of the burner to be explained in detail.

Representative examples from their range of C.4, C.6, and C.8 oil engines were exhibited by **Rolls-Royce Limited,** of Derby, including a normally aspirated C.4 4-cylinder engine, with a power range of 60 to 125 bhp. This engine is also available in supercharged form, with a power range of 70 to 167 bhp.

Of the C.6 engines, a 6-cylinder supercharged engine, with a "Mathway" gearbox, was exhibited. This engine, with its power range of 100 to 250 bhp, is typical of Rolls-Royce high-power marine engines, as used in Admiralty launches, R.A.F. general-service pinnaces and rescue launches, and passenger launches. Other exhibits in this class included a fully sectioned 6-cylinder supercharged motorized engine, and a normally aspirated 6-cylinder vertical engine (illustrated) for general industrial application, with a power range of 80 to 185 bhp (supercharged, 100 to 250 bhp).

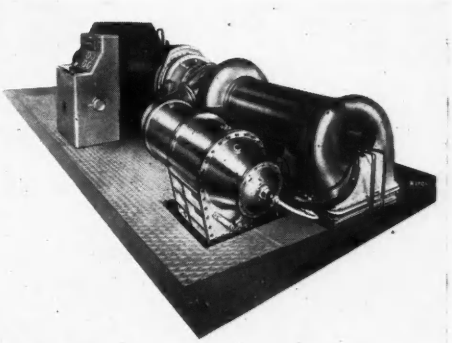


Of the C.8 engines, the exhibit comprised an 8-cylinder, horizontal supercharged engine for rail-car application. The normally aspirated engine has a power range of 100 to 246 bhp, while the supercharged version has a power range of 130 to 300 bhp.

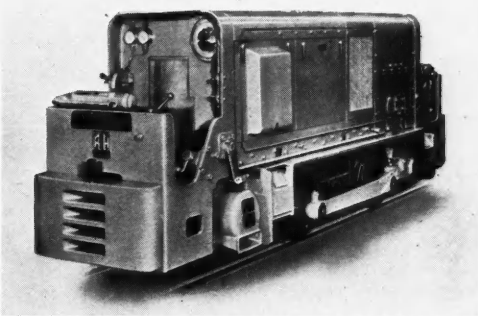
Features of the Rolls-Royce range of oil engines include the common bore and stroke for the entire range of 4-, 6-, and 8-cylinder engines, right- or left-hand build according to requirements, and a wide choice of auxiliary mountings and drives.

The most comprehensive display ever presented by **Ruston & Hornsby, Ltd.,** of Lincoln, associated with **Davey, Paxman & Co. Ltd.,** of Colchester, was shown this year. Exhibits representing the three main ranges of the Ruston-Paxman group's oil- and gas-burning power units were featured, including Ruston industrial and marine diesel engines, gas turbines, horizontal oil engines, and diesel locomotives, Ruston-Paxman industrial and Vee-form diesels, and Paxman light/medium-weight Vee-form diesels for traction and oilfield applications.

Of these, the RPH Series II is an extremely compact diesel engine, recommended for duties where small dimensions are of primary importance. The range comprises five engine sizes and provides powers from 120 to 670 bhp. The 4 RPH II exhibited is rated to give 167 bhp at 1250 rpm and is fitted with a torque converter.



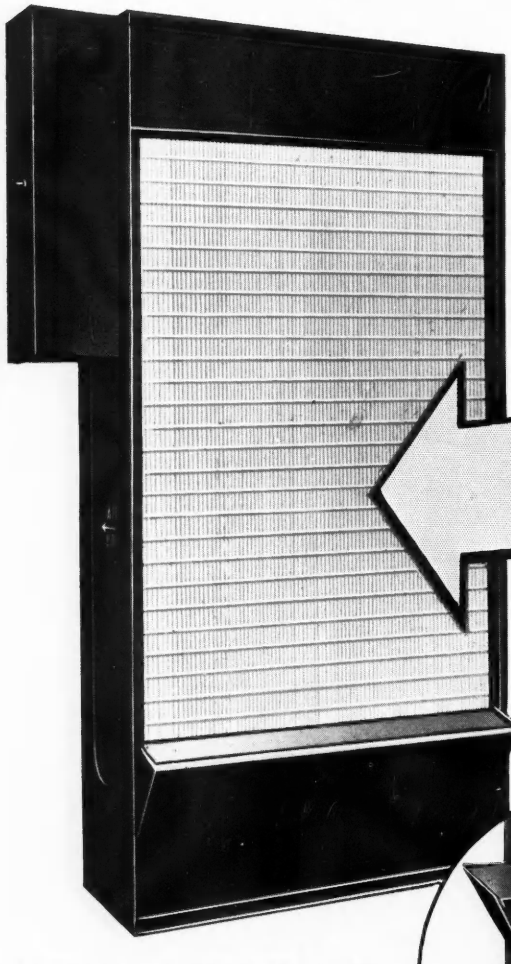
The Ruston gas turbine has become firmly established as a modern industrial power unit. This year, a standard "TA" gas turbine, with a maximum rating of 1410 bhp, was displayed, with covers removed to permit internal examination. The machine, which is arranged for burning oil fuel, incorporates features of special interest, including the air cooling system for the turbines and the fully kinematic type of construction employed, which facilitates rapid starting and stopping of the machine by ensuring that all hot parts are free to expand and contract as the gas temperature changes. The complete machine, a typical installation of which is shown above, weighs 5 tons and is 15 ft 9 in. in length.



Another interesting exhibit is the Mark LHG diesel mines locomotive illustrated, a 10-ton, 75-bhp, flameproof unit with a driving station at each end. The Ruston range of diesel locomotives includes machines for underground, narrow-gauge surface haulage and for shunting.

In addition to their well-known range of Type RF diesel engines, **Ailsa Craig Ltd.,** of Ashford, Kent, have exhibited for the first time their new RK Series of medium-heavy, and RA Series of heavy, diesel engines in a range of 30 to 90 bhp. The RK Series has been specially produced for fishing craft and work-boats, in addition to motor boats and cruisers. They embody many features which experience has shown to be of real value in this class of work, as well as in general marine propulsion and auxiliary service. The industrial and traction versions meet all requirements within the range of power. The RA Series is essentially a heavy-duty

for HEAVY dust loads



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MULTI-DUTY

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Automatic · Self-cleaning · Viscous

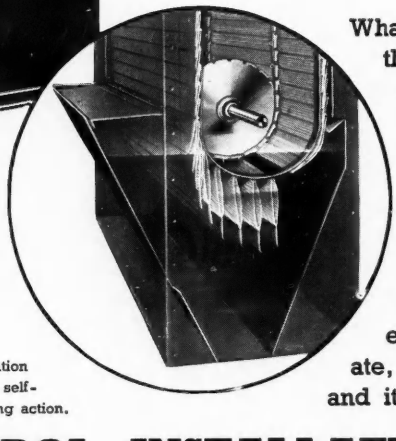


Illustration shows self-cleaning action.

Whatever the dust load the Multi-Duty filter maintains **constant** high efficiency – **constant** self-cleaning — and **constant** air delivery, with **no oil carry-over.** It is easy to install, economical to operate, simple to maintain, and it **DOES THE JOB.**

AIR CONTROL INSTALLATIONS LTD.

Ruislip · Middlesex · Ruislip 4066 (8 lines)

BIRMINGHAM Midland 1165 and 1367 · **MANCHESTER** Central 0679 and 0670 · **NEWCASTLE** Whitley Bay 23046 · **GLASGOW** Central 2023

engine intended for marine and industrial purposes of a kind where weight is not a main consideration.

In both series the enclosed flywheel is aft, the S.A.E. housing being arranged to carry in the marine models the integral reverse or reverse-reduction gear, or in the case of industrial and traction models the clutch or other power take-off. The crankshaft is extended at the forward end to provide a drive for suitable auxiliary equipment. Both types have forced-feed lubrication to the prefinished main and connecting-rod bearings, camshaft, overhead valve gear, and timing gears. The gear-type lubricating-oil pump is readily accessible by the simple removal of an inspection cover. Timing is carried out entirely by gears driving a high-level camshaft, which is arranged with lever-operated compression-release cams. The short push rods operate tulip valves. The flywheel and all working parts are totally enclosed. Cylinder heads incorporating the Ricardo whirlpool combustion chamber are individual to each engine cylinder, thus making them interchangeable throughout the series. Generous water cooling is provided for valve seats and fuel injectors, whilst safety-type stainless-steel expansion plugs are provided as a precaution against freezing and can be used for cleaning, when necessary. Easy starting, with a low fuel consumption, has been achieved and electric starting equipment is provided on all models as standard. Provision is made for a power bilge pump.

Other features include a full-flow lubricating-oil cooler and a full-flow " Auto-Kleen " filter, both built into the cylinder block and conveniently placed. A hand-operated pump is supplied as standard for emptying the sump, and there is a dip-stick level indicator. Slow-running horizontal plunger-type circulating water pumps, with easily accessible and large-diameter valves, give adequate cooling on the marine types. Industrial types are fitted with an efficient centrifugal pump. Both models can be supplied with two pumps for intercoolers and radiators. The crankcase is a monobloc casting, carried up to the cylinder heads in a one-piece box-section framing, giving utmost rigidity and strength, and ensuring perfect alignment between the cylinders, crankshaft, and camshaft. Wet-type renewable liners have two sealing rings. A special feature is accessibility, large inspection doors of light alloy being provided throughout the engine.

Entirely devoted to the display of their hydraulic infinitely variable-speed gears, **Carter Gears Ltd.,** of Bradford, Yorkshire, have exhibited for the first time their new Type " F " Size 14 Carter Gear. This gear, which provides an addition to what was previously known as the " Carter-Junior " range of variable-speed gears, is rated at 3 hp and possesses all the features of the smaller-powered gears.

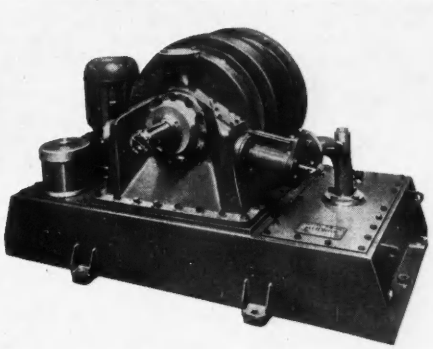
Also on view for the first time was a typical conveyor drive featuring a special form of electric remote control, which ensures that if, for any reason, the conveyor is stopped at normal operating speeds it can only be re-started at a slow speed. This is a safety feature of great value, preventing overloading the drive after stops and damage to materials on the conveyor.

In addition, there were displayed all standard types of speed control, several of which were on working drives illustrating their wide adaptability.

Of the many exhibits shown by **Fluidrive Engineering Co. Ltd.,** of Isleworth, Middlesex, two of the most interesting were the size 29 Dual Fluidrive and a Vulcan-Sinclair size 22¼ S.T. fluid coupling.

The principle of the Dual Fluidrive, which was exhibited for the first time, is based on two fluid circuits, which are filled or emptied by two scoop tubes, thus transmitting power either through the centre shaft or the sleeve shaft. This system is being developed for a number of purposes, including diesel railway traction, oil drilling, marine propulsion, and a variety of winches and hoists where reversing is required. The exhibit in question, with its two-speed gearbox, was constructed for a 500 hp diesel locomotive, the engine of which will be of the constant-horsepower supercharged type.

The range of Vulcan-Sinclair scoop-trimming fluid couplings is being extended to meet the demand for the driving of high-power, high-speed boiler feed pumps, turbo-compressors, gas boosters, and similar plant where a quick-response infinitely variable speed regulation is required, the driving motor being a squirrel-cage machine. The Vulcan-Sinclair size 22¼ S.T. fluid coupling is a type designed to meet requirements where driven speeds in excess of 3000 rpm are needed. This particular exhibit was shown driving a speed-increasing gear, the whole mounted on a common bedplate. With an input speed to the fluid coupling of 2950 rpm, the power transmitted at 4000 rpm of the output shaft is 2000 hp. The illustration shows a size 22¼ S.T. fluid coupling, without the speed-increasing gear and bedplate.



A feature of the S.T. type of fluid coupling is that there is no rotating reservoir, as with the scoop-control coupling, the oil being retained in a stationary reservoir tank when the coupling is at rest. A small motor-driven circulating pump delivers oil through the water-operated coolers into the working circuit, and the amount of oil therein, on which the speed of the output shaft depends, is determined by the position of the sliding scoop, from which the oil is returned to the reservoir tank.

Among a number of products shown by the member companies of the John Thompson Group, including a true-to-scale model of Thompson boiler plant at the C.E.A.'s Tilbury generating station, **John Thompson Water Tube Boilers Limited** exhibited their " Minipac " boiler, which is being developed in a range of sizes from 3500 lb/hr evaporation, with working pressures up to 250 psi. These boilers are completely automatic, with all accessories built in, so that they can be delivered to site ready for use. The boiler actually exhibited has an evaporation of 5000 lb/hr from a horizontal, flat-ended cylindrical boiler shell only 4 ft 9 in. diameter by 5 ft long. Two main flue tubes are fitted with special oil burners, giving a short non-luminous flame. A two-pass system is used to ensure maximum heat transfer. The boiler uses gas oil or diesel oil without oil heating. It can also be arranged for light residue oils.

A package boiler of different design was exhibited by **John Thompson (Wolverhampton) Limited.** Like the " Minipac," this is a self-contained unit, with auxiliaries built in. Using heavy fuel oil, the boiler shown has an evaporation of 5175 lb/hr at 125 psi working pressure. The rotary oil burner, induced-draught fan, feed pump, and other auxiliaries are automatically controlled from a central control panel. The boiler shell is 5 ft 6 in. diameter by 10 ft long. One

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"How are other engineers using Ferobestos?"

Engineers in all branches of industry have solved constructional problems with Ferobestos Plastics.

Here are just a few of its applications:—
Bushes · Coupling Discs · Guides · Bearings Gears · Rollers · Piston Rings · Wearing Slippers Mounting Pads · Compressor Blades · Thrust Washers.

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J. W. Roberts Limited, who specialise in engineering and structural applications of asbestos, have set up a new department, entirely devoted to the development of Ferobestos Technical Plastics. This ensures a prompt, efficient service to engineers and designers.

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main flue is surrounded by two concentric rings of fire tubes, serving as second and third passes for the gases of combustion. Access to tubes is facilitated by large circular end doors, each swinging open on its own integral crane. The complete unit is built on its own sub-frame, allowing for lifting as one. The boiler is self-setting and a simple concrete slab is all that is required for foundation.

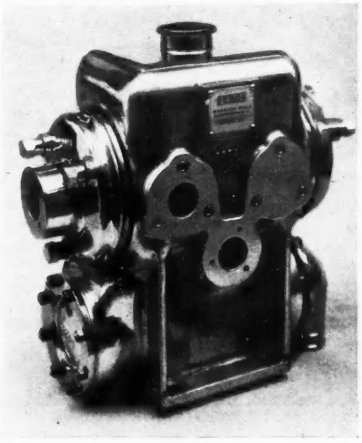
A small twin de-ionization plant was shown in operation by **John Thompson-Kennicott Ltd.** This type of plant has been developed by the company to produce water of the very highest purity for modern power-station plant and for certain industrial processes where such high purity is required. The process employs pressure vessels containing synthetic resins, the contained salts in the raw water being converted to acids in one vessel, and the acids being removed in the second vessel. The resins in these cation and anion exchangers are re-generated by acid and alkali treatment respectively. The ion-exchange vessels and their pipework are constructed of rubber-lined mild steel. Pumps or injectors are used for adding the reagents, and the whole process can be made automatic.

The chemical engineering department of **John Thompson (Dudley) Limited**, showed exhibits representative of their work in the field of pickling and acid-recovery plant. A working model demonstrated a rotary process plant supplied for pickling coil strip. A full-scale pickling cage used in this plant was available for inspection, together with a measuring vessel and an example of a lead-covered copper coil for steam heating the acid baths. A model of a complete acid-recovery plant was also on show.

The John Thompson Group also showed some fabricated samples of the type of work they are carrying out in various metals for atomic-energy projects, including the Dounreay "Fast Breeder" reactor station. In addition, they showed diagrammatically the form of both the gas-cooled, graphite-moderated stations and the fast reactor stations on which their engineers are collaborating with the United Kingdom Atomic Energy Authority.

In addition to a wide range of other cooling units, **Serck Radiators Limited,** of Birmingham, exhibited their fuel-cooled oil cooler, which is built throughout of light alloys and which safely handles kerosene/lubricating-oil pressure differentials of the order of 2000 psi.

Another interesting exhibit was the W-type combined unit illustrated, which comprises a streamlined header tank made to mount on an oil engine. Embodied in the tank is a tubular-type heat exchanger, which cools the engine-jacket water, using raw water (sea or river water, or town mains) as coolant. The cooled jacket water then passes through a second heat exchanger, to serve as a coolant for the engine lubricating oil. Thus, on starting, with a thermostatic valve by-passing the upper heat exchanger, the jacket water rapidly warms up and at the same time preheats the oil in the lower exchanger. As a result, working temperatures are swiftly established and excessive wear due to cold-starting is considerably reduced.



Among a wide range of products, including slip-ring induction motors, switchgear, fusegear, transformers, and self-regulating alternators fitted with the patented "Amplidex" system of control, the **Brush Electrical Engineering Co., Ltd.,** of Loughborough, exhibited their type FQT 15-hp, compound-filled, flameproof squirrel-cage motor.

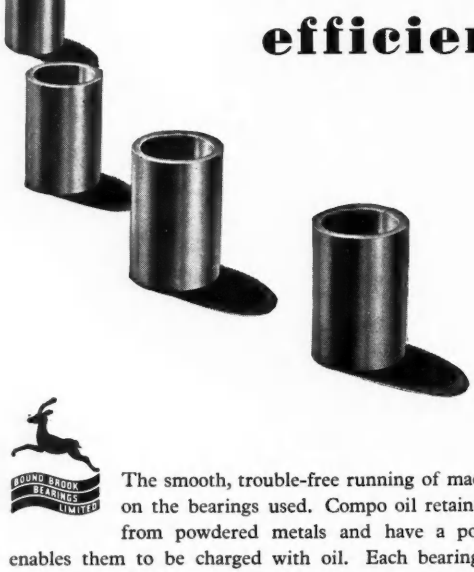
This motor, the first of its type introduced into Great Britain, is Buxton-certified for group L and 2 atmospheres, and can be supplied as a self-cooled type from 10 to 65 bhp, or as a blow-over type from 10 to 110 bhp. While its general construction complies with the standard design of Brush flameproof motors, it has an added outstanding feature of compound encased stator windings. The compound filling used is a self-setting material which is not thermoplastic. The free air space within the diameter of the rotor is further reduced by casting aluminium blocks onto the bearing housings, of such a shape as to fit as close to the rotating members of the rotor as possible and also the bore of the filling compound.

Internal condensation and other troubles, such as infiltration of dust in the bearing grease, are primarily attributed to breathing. Brush compound-filled motors reduce breathing almost entirely and are therefore suitable for mines, quarries, chemical plant, and similar industries. Longer life and reduced maintenance are ensured, and the temperature rise in these motors is no greater than in the orthodox type of equal frame size, since heat conduction is improved by the filling.

Among a wide range of products, including electronic equipment, lamps and lighting equipment for ships, shipyards, dockyards, and factories, electric motors, and switchgear, **The British Thomson-Houston Co., Ltd.,** of Rugby, exhibited an interesting multi-motor control board, which is one of two similar panels ordered by Vickers Armstrong (Shipbuilders) Ltd. for one of their new ships under construction. This equipment is the starboard panel for controlling auxiliary motors and consists of an auto-transformer starter and eleven direct-on-contactor starters, all this gear being grouped together in sheet-steel cubicles to form a flush-fronted board of pleasing appearance. The starter units are of the withdrawable plug-in type, permitting maintenance to be carried out with a minimum of inconvenience; if necessary, the individual starters can be removed completely and can be replaced or interchanged with an identical unit.

Other equipment designed specifically for marine applications included marine radar and a propeller rotation indicator and revolution counter. This latter equipment is of particular interest, as it constitutes a departure from the conventional methods employed for remote indication of propeller speed. Selsyns are used in this system developed by BTH, one such unit being coupled to the propeller shaft and the other to operate the indicating instrument. The units are tied together electrically by a light five-core cable, and the angular movement of the "transmitter" selsyn on the propeller shaft is reproduced at the "receiver" end without error. A single transmitter can be used to supply more than one receiver, if necessary, so that an indication of propeller movement (and revolutions, if required) can be provided on the bridge, as well as in the engine-room.

Bearing on mechanical efficiency



The smooth, trouble-free running of machines depends largely on the bearings used. Compo oil retaining bearings are made from powdered metals and have a porous structure which enables them to be charged with oil. Each bearing is therefore its own self-lubricated unit and maintains a film of oil between bearing and shaft whatever the speed or load. This is highly important in those applications where periodic lubrication is unlikely, or difficult to achieve. The close tolerance finish of Compo eliminates machining or other treatment prior to fitting and ensures the highest standard of mechanical efficiency. May we tell you more about them?

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BEARINGS

★ **BOUND BROOK BEARINGS LTD.**, are also specialists in the fabrication of sintered components by the powder metallurgy process

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Also displayed were electric motors specially designed for marine use, a "Magnestat" automatic voltage regulator, and a demonstration of the operation of a BTH electromagnetic coupling-alternator, two of which have been installed in a ship as part of the main equipment in the engine room. At sea, the units operate as conventional electromagnetic couplings between the main engines and propellers, each transmitting 630 bhp at 250 rpm; in harbour, however, they are used as alternators (driven by the main engines) each developing 500 kW, 440 V, three-phase, at 300 rpm, for supplying the extensive cargo-handling machinery.

Mention should also be made of the exhibit showing the 7000 shp amplidyne-controlled constant-current diesel-electric propulsion equipment in three ice-breaking cargo vessels which have recently gone into service for Russian owners. In each ship, the propelling machinery consists of four eight-cylinder De Schelde-Sulzer diesel engines, each coupled to a 1392 kW, 400 V BTH d.c. generator; the single screw is driven by a 7000 shp, 150 rpm, 800 V double-armature propulsion motor.

Among a number of interesting items, including various types of industrial heaters which can now be adapted to oil and gas burning, as well as coke burning, **Tangyes Limited,** of Birmingham, exhibited a 70-ton general-service press, a 16-ton sleeving press, two horizontal diesel engines, and various pumps, including centrifugal and horizontal steam pumps.

Other interesting exhibits featured included a display of their super-lightweight hydraulic jacks, and their hydraulic climbing jacks, which have recently proved very popular in the building industry for use by concrete workers employing the moving-form method of building construction.

Exhibits by **Imperial Chemical Industries** included representative products of the I.C.I. Metals Division and Nobel Division, and of Marston Excelsior Ltd.

The I.C.I. Metals Division showed non-ferrous tubes and plates in "Kunifer" 30 and 30A, "Alumbro," "Resisco," Admiralty and 70/30 brass for condensers, coolers, and other special plant for land and marine power stations, and for oil and sugar refinery plant. Titanium and titanium-alloy strip, sheet, tubes, wire, rods, sections, forging stock, and ingots were also featured, together with "Kunifer" 5 (copper-nickel-iron) sheet and tube for sea-water trunking, "Integron" finned tube (including bimetals and steel) for rapid heat exchange, bimetal tubes and plates, and refrigerator and other small-diameter copper tubing in long-length, soft-temper coils. "Kynal" aluminium-alloy extrusions, sheet, and plate, for land and marine transport applications, and "Kynal" aluminium busbar and jointing compound were also shown, as well as examples of heavy and medium metal press-work undertaken by the Metals Division and the "Kynalok" Secret-Fix cladding system for roofs and walls.

A special exhibit of silicones was staged by I.C.I.'s Nobel Division and included the use of silicones as parting or release agents for all types of moulding processes. Special-purpose silicone rubbers, in the form of gaskets, seals, and other mouldings for use at high and low temperature extremes, and also the use of silicones as a basis for heat-resistant paints and as a weld-backing compound were also displayed.

Marston Excelsior Ltd. showed examples of heavy-gauge fabrication in aluminium alloys, comprising pipe work, welded vessels, and structures, using the argon-arc process. Aluminium-alloy hatch covers and light-gauge fabrications, including examples of heat exchangers in light alloy of dip-brazed construction for industrial and marine use, were also featured. A further section showed laminated plastic ducting and components for a wide range of applications.

A feature of the exhibits provided by **Tecalemit Limited,** of Brentford, Middlesex, was their new centralized lubrication system. This new equipment incorporates a hand- or power-operated pump charging a series of injectors, which, in turn, service a series of individual points. The injectors are of simple but robust design and entirely dispense with the use of springs, cup leathers, or ball valves, which so often can be sources of trouble in this type of system. The actual injection of the lubricant is accomplished by a two-stroke cycle of the main piston within the injector. The shot from the first line charges the injector cylinder with lubricant, at the same time raising the main piston, whilst that from the second line provides the pressure for the return stroke, which ejects the lubricant into the bearing. Under standard operating conditions output can be varied from 0 to 2·57 cc per injection by a simple external adjustment. This system provides an excellent service, where a measured, intermitent lubricant supply is required.

Another new item of equipment is the impulse pump. This is a ratchet-operated lubricator which will discharge a shot of oil at predetermined intervals. The ratchet arm controls the movement of a cam which releases a spring-loaded piston discharging the lubricant.

One of the most interesting exhibits was a new departure for the Company—a welding-fume extractor. The design provides a means of dispersing fumes created during welding by using compressed air to create a clean-air breathing zone within the welder's face-mask; this consists of a specially designed welding mask equipped with an air tube and accurately disposed jets, which are coupled to a convenient air supply.

The Tecalemit "falling-drop" lubricator was another new item of equipment exhibited. This lubricating-oil pump provides an efficient method of pumping oils, including those containing additives or detergents. The design of this lubricator enables several pumps to be coupled together over a common reservoir.

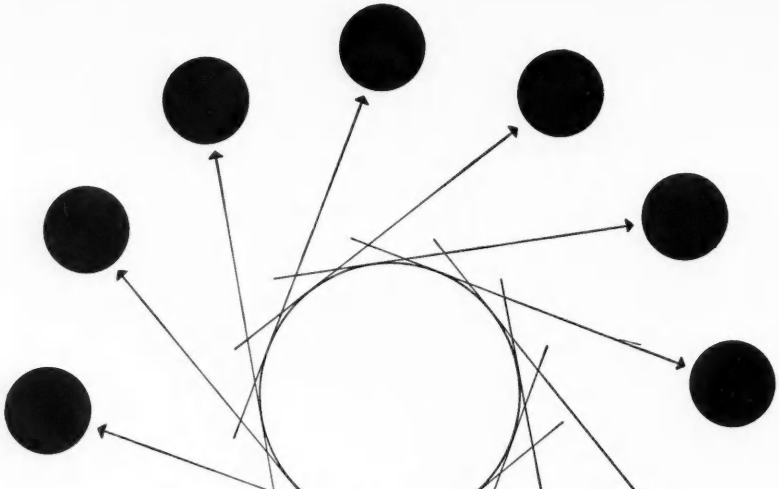
Although mainly devoted to a display of crucibles, refractories, and furnaces, including oil-fired hydraulic lip pour furnaces, miniature crucible furnaces, and bale-out furnaces, **The Morgan Crucible Company Ltd.,** of London, S.W.11, exhibited many other products of interest to engineers, technicians, and designers.

An item of particular interest to marine engineers was a section of a marine-boiler wall made from MR.60 Super Firebrick, utilizing an anchor brick and heat-resisting anchors. Other marine applications included burner quarls made from MR High-Temperature Castable (service temperature 1600°C) and MR Plastic Mouldable (service temperature 1650°C).

Morganite sintered-metal clutch facings were also featured and included a display of some of the types which are available for machine tools, coal cutters, electrical and mechanical starters, and actuators. In addition, an extremely wide range of engineering parts made from Morganite carbon was available for inspection, together with a number of finished components which incorporate this material, including a pump-shaft sealing gland, a motorized steam valve, resistance heating equipment, a submersible pump, and a petrol metering device.

An interesting development, displayed for the first time, is carbon-lined stainless-steel tubing, manufactured jointly by the Morgan Crucible Company and the Talbot Stead Tube Co. Ltd. This tubing is marketed by the latter Company under the trade name of "Metica."

Other exhibits of interest included a demonstration laboratory furnace, utilizing MI low heat-storage refractory bricks, and a new type of silicon carbide electric-furnace element—"Crusilite." This element is available for high-temperature furnaces over a range between 800 and 1575° C.



A flush of tangents

Though going off at a tangent may suggest a butterfly brain to many people, it means something entirely different to us. For, with a subject as diverse as electricity, development is always likely to shoot off in unexpected directions. We encourage this sort of activity in Crompton's. At the moment there are twelve sections which make up the Crompton Parkinson organisation, all of which began life as tangents shooting off from the parent body. They are now well established and respected, each dealing with its own flush of tangents. This is the nature of progress. New discoveries are pursued and developed—eventually they are assimilated and become part of the accepted order of things. This is how the firm of Crompton Parkinson has grown and why it will keep on growing.

When it comes to electrical equipment . . .

you've got to hand it to Crompton Parkinson LIMITED

ELECTRICAL EQUIPMENT

MAKERS OF ELECTRIC MOTORS OF ALL KINDS · ALTERNATORS AND GENERATORS · SWITCHGEAR · B.E.T. TRANSFORMERS · CABLES · INSTRUMENTS LAMPS · LIGHTING EQUIPMENT · BATTERIES · STUD WELDING EQUIPMENT TRACTION EQUIPMENT · CEILING FANS

** There is a controlling factor common to all tangents which stops them getting out of hand. No tangent can exist as such unless it retains close contact with the circle which is its parent body. That's just the way we like things at Crompton's.*

CROMPTON PARKINSON LTD., CROMPTON HOUSE, ALDWYCH, LONDON, W.C.2. TEL: CHANCERY 3333

Of the many types of electric motors exhibited by **Newman Industries Limited,** of Yate, Bristol, one of the most interesting is their new gasworks-type motor, which has been designed to meet the special requirements of gasworks and ordinance-factory engineers and, as such, is dust-tight, weatherproof, and hoseproof. By simple additions and modifications to their existing British Standard dimension motor, Newman have achieved a design for the new type which is fully protected for operation in dusty, dirty, or wet atmospheres. Furthermore, by selecting their B.S. range as the basis for the gasworks-type motor, it can be offered immediately in the full range of from ½ to 25 hp.

The only outward difference between the ordinary Newman B.S. motor and the new motor is the terminal box. On the gasworks motor a flameproof type of box has replaced the standard version. This box has wide flanges and the terminal mounting posts are embedded in separate synthetic-resin-bonded moulded insulators. There is therefore an effective seal between the terminal box and the inside of the motor, positively preventing the entry of dust or water. The box can be arranged for direct-conduit entry (in four positions) or it can be equipped with a sealing chamber and armoured glands. In either case wide flanges or extra-long threads prevent the ingress of dust. Bearings are doubly protected by "wiping"-type seals, fitted in addition to the normal bearing closures. Two other features are the use of stud-type bearing caps and a locknut to secure the keyed fan to the shaft, in place of the more usual circlip. In addition to the normal impregnation, the end windings are given a coat of special varnish which is highly resistant to moisture and dust, and, to ensure that moisture or dust cannot creep in along securing bolts, all castings are arranged so that bolts do not anywhere break into the inside of the motor. As a final precaution against dust, the end-bracket joints are coated with a sealing compound during assembly.

A representative selection of all other types of Newman motors was also exhibited.

Among a comprehensive selection of their products, including "Lectrodryers" and a 35 kW low-frequency induction melting furnace for aluminium, zinc, and their alloys, **Birlec Limited,** of Birmingham, exhibited their new Birlec HRP 50 furnace, designed to provide all the advantages of electric heating, including a temperature uniformity to ± 10°C over a range of 700 to 1050°C.

To assist the handling of heavy charges the generous charge space has been left clear, the elements being entirely removed from the side walls and secured by hook-pins on the underside of the arched heating-chamber roof. Additional elements are located in slots beneath the hearth slabs, to assist temperature uniformity; these elements are easily removable for inspection or replacement. The standard nickel-chromium ribbon elements are protected from the possibility of mechanical damage from castings or similar pieces being pushed into or dragged out of the furnace. An additional heating element is inserted into the door brickwork, to counteract inevitable heat losses at this point. This element is separately zoned, and switches off and on as the door opens and closes. This furnace also incorporates an exceedingly hard-wearing hearth of high-grade alumina firebrick, particularly resistant to abrasion and spalling. Furthermore, by virtue of its design, it is a relatively easy furnace to keep clean, even in the dirtiest conditions.

The door gear is completely enclosed within the furnace casing, the counterweighted mechanism extending over the top of the furnace, with the weights located in a compartment at the rear. This compartment is also used to accommodate the two transformers (one for the main elements and the other for the door element), access also being available to the element connections. The furnace control panel has been similarly redesigned,

the contactor panel being located beneath the temperature indicating control panel. Coloured lights signify "power on" and "heat on."

The Birlec HRP is available in two standard sizes; the HRP50 exhibited (illustrated) is rated at 50 kW, with charge-space dimensions of 4 ft length by 2 ft 6 in. minimum width by 1 ft 6 in. minimum height. The larger model, rated at 70 kW, has dimensions of 5 ft × 3 ft × 1 ft 6 in.

Many examples of the use of the heat-, corrosion-, and abrasion-resistant Deloro Stellite hardfacing alloys in practically every industry were exhibited by **Deloro Stellite Limited,** of Birmingham. Of particular interest among valves, pump sleeves, and other chemical-plant components, agricultural equipment, forging tools, knives, diesel-engine valves, rockers, etc., were examples of a recent development, the tipping of bandsaw teeth with Stellite. In addition to a longer working period between regrinds, the effective life of a Stellite-tipped bandsaw is considerably increased and, even when it does finally become worn, the bandsaw may be rendered "as-new" by simply and easily re-tipping the teeth with Stellite.

Deloro Stellite hardfacing alloys are deposited on tools and equipment by any conventional welding process and, in order to demonstrate the ease of application, there was in operation throughout the exhibition a complete oxy-acetylene welding bench and an arc-welding booth, the latter being a completely new feature. A prominent feature of the display comprised many different examples of Deloro Stellite precision castings for resistance to heat, abrasion, and corrosion, and also on view was a complete range of tipped tools, tool bits, milling blades, centres, work-rests, and drills.

An improved hydraulic 15-ton press, which combines high performance with remarkably compact and low-weight machinery, was exhibited by **Pilot Works Ltd.,** of Bolton. Based upon their Model No. 4, this press (illustrated) introduces modifications and refinements which have greatly increased operating speeds. These improvements include an additional gear pump in conjunction with a twin-cylinder plunger-type pump; an integral oil container; operation by hand lever; and a new design of rotary-type valve control. Also, the stroke has been increased to 8¾ in. and daylight to 16¾ in.

The approach speed of this new press, designated Model No. 5, is approximately 25 feet per minute, or 1·75 sec full down-stroke. Return speed is approximately 35 fpm, or 1·25 sec full return stroke. Pressing under load is about 25 in. per minute, or about 2·4 sec per inch. Maximum down-stroke pressure is 15 tons,

FBC sealed bearings

A manufacturer can save money and reputation with FBC sealed bearings:

1 **In design; they give you greater compactness; you don't have to allow room for a separate seal. The bearing is exactly interchangeable with the ordinary standard bearing.**

2 **In machining; you don't have to machine a place for a seal, or provide a polished surface for the seal to ride upon.**

3 **In safety; this seal cannot form stress-raising scratches in your shafts.**

4 **The sealing ring is unaffected by ordinary lubricants, being of synthetic rubber. Seal can be on one or both sides.**

5 **You don't have to rely on some unknown user to lubricate the bearing.**

FBC
TRADE MARK

ALL-BRITISH BALL AND PARALLEL-ROLLER BEARINGS

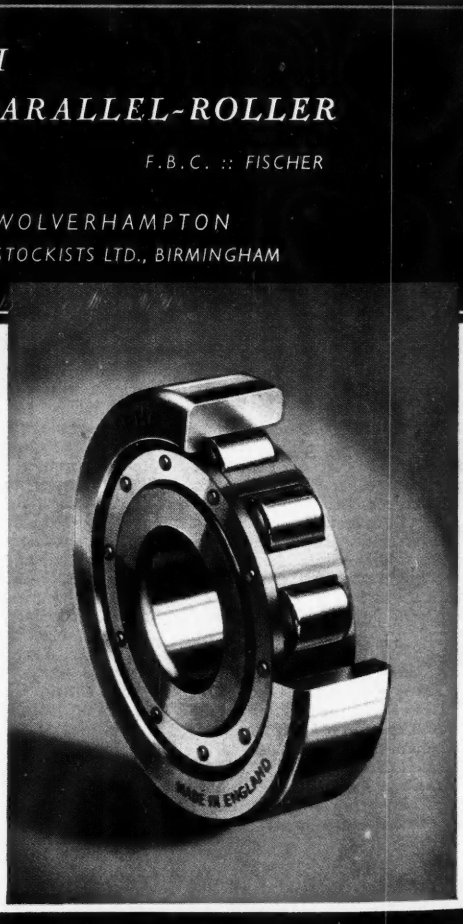
F.B.C. :: FISCHER

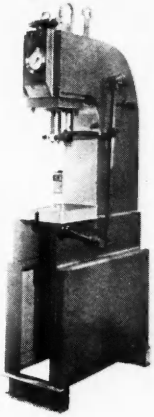
FISCHER BEARINGS COMPANY LTD., WOLVERHAMPTON

FISCHER BEARINGS CO., LTD. and TIMKEN-FISCHER STOCKISTS LTD., BIRMINGHAM are both subsidiaries of BRITISH TIMKEN LTD.

FBC parallel-roller bearings

Fischer parallel-roller bearings, as illustrated, are made in an extensive range. In addition, we make roller bearings to U.S. types and sizes. Other Fischer bearings cover a wide range of types and sizes of ball bearings, ranging from miniature bearings for instruments to U.S. sizes and 'specials', both ball and roller.





and maximum up-stroke pressure is 5 tons. By manipulation of a small hand-wheel, the down-stroke pressure is adjustable from 1 to 15 tons, up-stroke pressure being similarly adjusted in proportion.

In addition, two well-tried machines from the Pilot range, their power cropper and hydraulic 12-ton press, were exhibited.

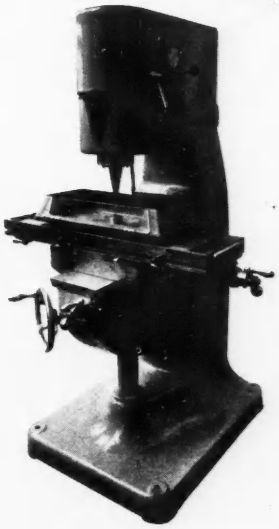
A range of "Eclipse" permanent magnets in all types of industrial applications and "Eclipse" magnetic tools, for use in all forms of work-holding, were featured by **James Neill & Company (Sheffield) Limited,** of Sheffield.

Of particular interest was a new size of permanent-magnet chuck having a working area of 7 × 4 in. and an overall height of only $1\frac{1}{16}$ in. This new model is ideally suited to toolrooms for use on small machines and, in conjunction with the standard 8 × 5 in. "Eclipse" swivelling angle plate, provides a small swivelling chuck. A large selection from the range of "Eclipse" rectangular chucks was available for demonstration, together with accessories for magnetic chucks. A circular chuck not previously exhibited is the 12 in. diameter heavy-duty circular model. This chuck has been designed for use on larger lathes, where heavier workpieces and cuts are experienced. The "Eclipse" magnetic aids to production, also featured, included special magnetic tools for holding workpieces during welding and assembly operations.

In addition, the display included a comprehensive range of permanent magnets of types incorporated by electrical and other manufacturers in their products, typical applications represented being loudspeakers, television, telephones, electricity meters, measuring instruments, generators, motors, magnetos, etc.

New ultrasonic apparatus, ranging from high-power industrial ultrasonic machining and cleaning equipment to compact drilling and soldering equipment, was featured by **Mullard Ltd.,** of London, W.C.1.

Of special interest was a 2 kW ultrasonic machine tool, designed to carry out all normal production machining processes (drilling, milling, lapping, etc.) on hard and brittle substances. This is a robust, fully-engineered machine, capable of reliable operation in the hands of operators accustomed to working with normal precision machine tools. This 2 kW ultrasonic tool (illustrated) is a prototype equipment which has been developed at Mullard Research Laboratories. Standard generators and transducers are employed. The tool shown was fitted with compound tables and a precision vertical-feed movement. The power input to the drill is eight times greater than the input to the Mullard drill, type E.7690, now in production. As a result, the cutting speed of deep holes has been greatly increased. In addition, the capacity has been increased, and tools up to 2 in. in diameter can be used.



Another interesting exhibit, also shown for the first time, was a completely mechanized ultrasonic cleaning plant, built in conjunction with Kerry's (Great Britain) Limited. This is a fully automatic unit incorporating the latest Mullard high-frequency ultrasonic generator and is suitable for removing loose contamination (e.g., swarf, lapping compounds, oil, and grease) from such engineered parts as ball races and hydraulic-valve components. A similar plant, using a Mullard low-frequency ultrasonic generator can be employed in cases where it is necessary to remove tenacious films from components. An important part of this apparatus is a system for the continuous filtering and purifying of the cleaning fluid. Ferrous particles are removed by a magnetic filter, while gauze, ceramic, and paper filters remove particles down to as low as 1 micron in diameter.

A comprehensive range of dial thermometers, recorders, and controllers was exhibited by **The British Rototherm Co. Ltd.,** of London, S.W.19, and included the well-known bimetal-actuated Rototherms with a wide variety of dial ranges, presentations, stem lengths, and diameters for marine, industrial, and laboratory purposes. Other items with bimetal actuation included maximum/minimum indicating and

Contamination

Unless specially built for the purpose, rubber hose subjected to oil or acid contamination will be permanently damaged — its life will be cut, and operating losses will result.

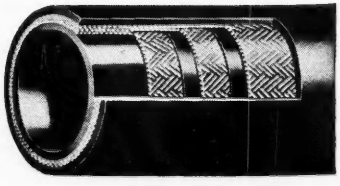
Goodyear make a wide range of hoses, each type built for a particular purpose. Oil, greases, paints and chemicals — to mention but a few materials — are handled by Goodyear hoses tailored for the job. All hoses — but especially those for water or air — will last longer if kept free of contamination by materials they are not built to carry.

Remember this: Every Goodyear hose is 'job-designed' to give maximum efficient life, and with proper installation and maintenance, will outlast all others.

Goodyear Hose makes work flow faster — at lower cost

AIR HOSE (Style 273 x 31)

The Standard Air Hose is designed to meet the general industrial need of a high quality flexible hose for use with air compressors and light or medium tool service. Lubricants in the air will not cause the tube to swell. The controlled bore of this mandrel-built hose, makes it ideal for use with couplings.



GOODYEAR INDUSTRIAL RUBBER PRODUCTS

INDUSTRIAL HOSE · TRANSMISSION BELTING · V-BELTS · CONVEYOR BELTS

control/alarm thermometers, with special designs for diesel engines, and for petroleum, chemical, and most industrial applications.

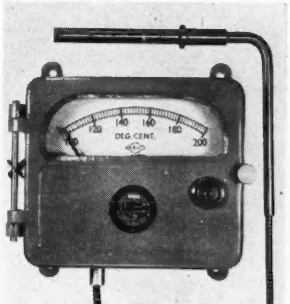
A range of distant-reading and rigid-stem models of mercury-in-steel thermometers, with 4, 6, 8, and 10 in. dials, wall or panel mounting, in modern-styled indicator cases, was also exhibited, together with designs for special applications, including diesel-engine exhaust-gas thermometers with anti-vibration heads. In addition, a wide range of vapour-pressure thermometers, available as distant-reading and rigid-stem models, for industrial and other purposes, and with dial sizes from $2\frac{1}{2}$ to 8 in., was featured, together with pressure gauges to match the mercury-in-steel and vapour-pressure thermometers.

Other exhibits included a range of single- and dual-pen mercury-in-steel temperature recorders, wall or panel mounting; wet- and dry-bulb recorders; portable recorders; and the "Talligraph" process batch recorder. Also shown was a range of single- and dual-pen, pressure, vacuum, and compound recorders, to match the mercury-in-steel temperature recorders.

Exhibits by **Air Control Installations Ltd.**, of Ruislip, Middlesex, included advanced types of equipment for dust and fume control, a range of dry and viscous air filters, an air-conditioning unit, various types of fans and midget blowers, a waveguide dryer, and a compact humidifier for textile, tobacco, paper, and similar applications.

The "Dusgard" unit exhibited represents an advance in the problem of controlling dangerous invisible dust from stand grinders. It incorporates the patented technique of "external dust control" and is exclusively manufactured by the Company. Another interesting exhibit was the "Rotoclone," a highly efficient dust-control equipment of advanced design, for wet or dry collection. Two types were shown, i.e., a dynamic precipitator for the dry collection of almost all types of granular industrial-process dust, and a hydrostatic precipitator, in which the cleaning action is obtained with an inverted S-shaped water curtain, and which is highly effective in collecting most types of process dust.

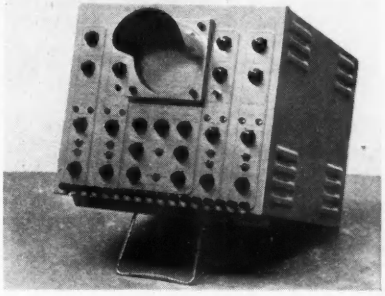
A wide range of instruments for indicating, recording, and controlling pressures and temperatures was exhibited by **The Accurate Recording Instrument Co.**, of Morden, Surrey. A typical example (an indicating thermostat) is illustrated.



Amongst their new products was a complete range of pressure gauges and dial thermometers, from 3 in. upwards. These instruments are mounted in strong aluminium-alloy cases, splashproofed and dustproofed. The design and construction of the mechanism of these instruments, as well as of their cases, incorporate many valuable features. The pressure gauges cover ranges from inches water-gauge up to thousands of pounds per square inch and may be fitted with various additions, such as electrical contacts, maximum pointers, pulsation and vibration dampers, overload protection, etc. The dial thermometers cover ranges from as low as $-240°F$ to $+1000°F$, and may be of the vapour-pressure, the mercury-in-steel, and the "Aric" patented fully compensated liquid-expansion types. They may also be fitted with numerous additions in the form of electrical contacts, maximum pointers, overload protection, etc.

New instruments which were exhibited included a patented gas-indicating thermostat, developed in co-operation with the North Thames Gas Board, and a differential-pressure indicator and transmitter, which may also operate recorders and controllers and which was developed especially for the Atomic Energy Authority.

Two new items of equipment, a four-channel oscilloscope (illustrated) and a portable engine indicator, were included among the exhibits of **Southern Instruments Ltd.**, of Camberley, Surrey. The former instrument is a general-purpose oscilloscope, on which four entirely separate oscillograms can be viewed or photographed simultaneously. Its outstanding feature is a flat-faced, four-gun type of cathode-ray tube.



An instrument of this kind is of the greatest value to the research worker or engineer engaged on developing or testing new devices. All kinds of measurements can be made, not only of electrical quantities but of physical quantities, such as pressure, force, strain, vibration, and acceleration, by connecting suitable transducers and auxiliary amplifiers. The user can see an oscillogram display on the screen representing four completely independent variables and he can observe the relative sequence and timing of the events and so interpret the phenomenon under investigation. Photographic records can easily be made by means of specially designed recording cameras. An important feature is the separation of the oscillograph unit proper from its power supply unit, ensuring freedom from spurious magnetic deflection produced by stray fields round the power transformer. The power unit can be located out of the way under a bench and the oscillograph unit then occupies the minimum space on the work bench. A tubular metal trolley can be provided to accommodate the oscillograph and power unit, so that the whole equipment can be conveniently moved about the laboratory. Controls are functionally grouped and the designations in red and black assist the user to memorize their position and function.

The portable engine indicator, Model M986, is a small, compact, transportable cathode-ray oscilloscope, designed for use with a wide variety of transducers for measuring physical quantities such as pressure, vibration, strain, etc. The instrument incorporates a 2·75-in. diameter cathode-ray tube which is fitted with a cylindrical telescopic light shield for use under high ambient light conditions. The necessary power supplies are derived from a rotary transformer which is driven from a 12-V accumulator. A two-stage direct-coupled

Even the best do better with

Eclipse

hacksaw blades

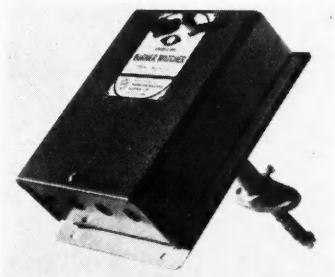
Made by James Neill & Co. (Sheffield) Ltd., and obtainable from all tool distributors.

UB3

Y-amplifier gives a maximum sensitivity of approximately 0·23 mm/mV. An additional stage provides electrical differentiation or integration when required. The repetition rate of the linear time-base may be varied from 5 to 5000 cps and can be free-running or self-synchronized to the Y-axis signal over a very wide frequency range without manual adjustment. This enables a steady picture to be displayed even while an engine is accelerating. A marker amplifier allows time or crank-angle degree marks to be superimposed on any signal. Provision is made for energizing electrical-resistance strain gauges or variable-resistance transducers from a small internal dry battery. All controls are logically grouped on the front panel and are colour-coded to facilitate operation of the instrument.

A complete range of automatic control equipment for industrial applications, heating and air conditioning, oil-burning equipment, diesel engines, air compressors, refrigeration plants, boilers, and all types of process plant was displayed by **Teddington Industrial Equipment Limited,** of Sunbury-on-Thames, Middlesex. This equipment covers controls for temperature, pressure, humidity, and liquid-level regulation and includes motorized and self-acting valves, solenoid valves, motorized actuators, electric compensator controls, safety valves, excess-temperature switches, thermometers, and sequence switches.

A special feature is the new Teddington " Spediflam" range of protection and control equipment. The new " Spediflam " Burner Watcher (illustrated), which is available with built-in or separate flue thermostat, incorporates a patented circuit and switch mechanism and has many unique features. It is designed for all types of automatic oil burners (continuous or intermittent ignition), has a built-in transformer to provide a low-voltage control circuit, built-in lock-out indicator lamp, and independent purge-period adjustment. The control unit is designed to provide an instantaneous start and fails safe under all fault conditions.



The company have also shown examples from their wide range of protection equipment for diesel engines, including the OV Mechanical Engine Watcher, which can be fitted to all types of diesel engine, and which shuts down the engine automatically when the lubricating-oil pressure falls, or the water temperature rises above preset safety limits. This device incorporates a patented indicator mechanism to denote the cause of shut-down.

The many ways in which the range of Wiggin high-nickel alloys meet the exacting requirements of industry for materials resistant to corrosion and high temperatures were illustrated by **Henry Wiggin & Company Limited,** of Birmingham.

Among the exhibits were carburizing boxes, a diesel-engine turbo-blower, exhaust valves of high-performance internal-combustion engines, examples of pyrometer sheathing, cores and dies used in the casting of aluminium-bronze components, and diesel-engine precombustion chambers. In addition, colour photographs depicted the use of nickel, Monel, Inconel, and Corronel B in various types of plant for the manufacture of processed foodstuffs, essential oils, caustic soda, fatty acids, and fertilizers, and also in pickling and other chemical processes. Further colour pictures showed some of the many duties to which the Nimonic series of heat-resisting alloys are being successfully applied in industry, e.g., for the high-temperature parts of vitreous enamelling furnaces, pottery-firing furnaces, and industrial gas turbines.

Engineers in all industries are now using more copper and copper alloys than ever before. This is not surprising since, among the copper-base alloys, materials will be found to meet almost every conceivable requirement in respect of mechanical properties, while other advantages include high thermal and electrical conductivities, and excellent resistance to corrosion and wear, as well as ease of manufacture and of assembly, e.g., by welding, brazing, or soldering. Some of these desirable characteristics were demonstrated by examples of finished and semi-finished products in copper, brass, bronze, etc., exhibited by the **Copper Development Association,** of Radlett, Herts.

The stand itself provided an interesting illustration of the variety of colours and finishes obtainable in copper and copper alloys, as it was faced with 7 in. squares of copper, brass, and nickel silver (" silver bronze ").

Displaying an extensive range of products with important applications in engineering and industry, the exhibits by **Ilford Limited,** of Ilford, London, were mainly devoted to photo-printing by the Ilford Azoflex process, with smaller sections covering industrial radiography and industrial photography.

The Azoflex process, now well known as a rapid and economical method of producing high-quality copies of plans, drawings, and documents of all kinds, was well demonstrated, together with a comprehensive range of Azoflex equipment, affording a choice of printing and developing machines, with large or small outputs, to meet every requirement. Also demonstrated (for the first time) was an alternative method of copying opaque originals, by means of the new Azoflex Transfer Foil, which offers exceptional speed of operation, obviates the use of processing chemicals, and yields a permanent carbon image which can be transferred to opaque or transparent paper or to suitable lithographic plates.

In the field of industrial radiography, a range of X-ray films was exhibited, together with specimen radiographs illustrating typical applications. Other items in this section included the new Ilford industrial X-ray viewer, type 8 ; this viewer is of special interest to industrial radiographers, as it provides both for the general examination of radiographs up to 14 × 17 in. by normal lighting and also for local inspection of small selected areas by intense light.

Exhibits in the Industrial-Photography section included examples of the more important applications of Ilford sensitized materials, including photographic reflex copying and the copying of engineering drawings with subsequent enlargement.

In addition to a comprehensive range of welding equipment, including automatic arc welding, resistance welding and heating, inert-gas electric arc welding, atomic-hydrogen arc welding, and metallic arc welding, **Metropolitan-Vickers Electrical Co. Ltd.,** of Trafford Park, Manchester, exhibited a beautifully constructed, sectioned scale-model of a Metropolitan-Vickers 100,000 kW turbo-generator, as supplied to the Central Electricity Authority, a rotor turning gear for marine steam turbines, an 80 kW diesel generating set, a 350 kW marine auxiliary set, comprising a steam turbine and 220 V d.c. generator, and a complete high-pressure cylinder for a 7300 shp marine turbine (maximum rating 8200 shp).

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THE money goes in — the ticket comes out! The traveller pays no thought to the magic that brought the ticket so quickly and easily to hand. But we suggest it would be worth *your* while to do so.

Westool Solenoids which help control the action of the London Transport Executive ticket issuing machines may be the means of increasing the efficiency of one of your processes. They can be employed to push, pull, open, shut, start, stop—in short, they are " the muscles of industry " with limitless applications.

Look around your works. See if you think there is a job of work that might be controlled by solenoids—*then get in touch with Westool for advice.*

Westool Series 2046 *D.C. Solenoid used in L.T.E. ticket machines manufactured by Messrs. Brecknell, Dolman & Rogers Ltd. of Bristol*

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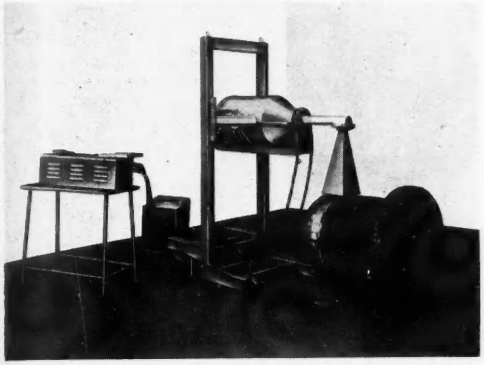
Export enquiries to Export Managers: Stamm & Partners Ltd., 59 St. Martin's Lane, London, W.C.2

Telephone: Temple Bar 5383 (10 lines) *Cables:* Stamstam, London

Tib. 18

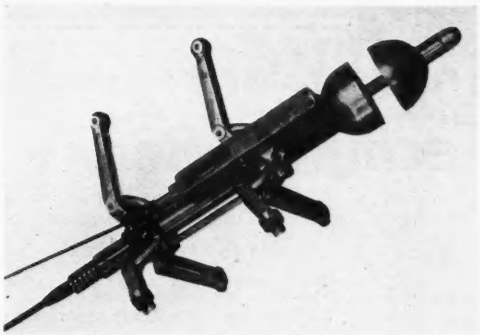
Exhibited by **Newton Victor Ltd.,** a subsidiary company of Metropolitan-Vickers, was their Raymax 150 industrial X-ray equipment (illustrated), the first to be designed and manufactured in Great Britain with gas insulation for both the X-ray tube and transformer. The absence of high-voltage cables, rectifying valves, and other ancillaries is an undoubted advantage when welded joints up to 1½ in. in thickness have to be examined on open constructional sites.



The high-voltage transformer and the associated transformer for heating the filament of the X-ray tube are both contained in a cylindrical steel tank, 18 in. in diameter. The X-ray tube is directly connected to the high-voltage transformer in the same tank, but the target or X-ray source is at the end of a small-diameter pipe projecting 18 in. from the main tank. The target extension tube can thus be inserted into hollow castings, or the complete transformer tube head can be placed inside pipes and pressure vessels larger than 18 in. in diameter. The use of sulphur hexafluoride for the insulation of both the transformer and X-ray tube keeps the weight to a minimum and at the same time improves reliability, owing to the absence of any of the problems associated with insulating oils at high temperatures. A robust metal box, conveniently arranged for transport, houses the controls for kilovoltage and milliamperage, with the associated instruments and exposure timer with a range of 0 to 55 minutes in intervals of 1 second, together with the usual switches and indicating lamps. A compact air-cooled water circulator provides a constant flow of water for cooling the X-ray tube target, which is at earth potential, thus making the equipment independent of the qualities and pressure of mains-water supplies. For laboratory use a gantry supports the tube head, so that it can be quickly and conveniently positioned in relation to the specimen. The tube head can be very easily detached from the gantry, when required.

The progress made since radioactive isotopes were first introduced was demonstrated by the exhibits of **Gamma Rays Limited,** of Smethwick, a distinctive feature of all their equipment being that, although produced for industrial applications and embodying every safety measure, attention has also been paid to neatness of design.

The central feature of their exhibits was the first industrial unit produced for use with powerful cobalt sources up to a strength of 20 curies, and caesium sources up to a strength of 2000 curies. As distinct from X-ray equipment, there is no question of tube replacement involved in this type of unit, the running costs of which are consequently virtually negligible. Owing to the high capacity of this machine, it is installed in an isolated room and its electrically operated control panel installed at a distance. In the event of a failure of the electric supply, the machine will fail " safe " and a similar circumstance would apply if any of the other electrical

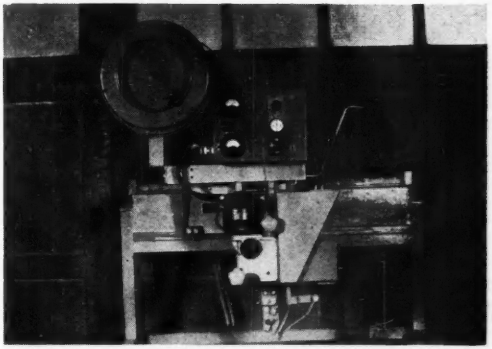


contacts were broken, or even if the door were opened. An electrically operated time clock mounted in the control panel commences, as well as terminates, the exposure. This machine will penetrate sections of steel up to 12 in. thick on fine-grain film with an exposure time of only a few minutes. Also on show were transportable models designed for cobalt-source strengths of 3 curies, 600 millicuries, and 250 millicuries.

A new unit recently introduced is intended for iridium sources up to a strength of 5 curies and for the examination of the welded pipeline which has just been laid from Sui to Karachi, Pakistan. With its pipe-clamp and tension film-holder it has proved itself to be a very quick and efficient machine for examining circumferential pipe welds from 6 inches o.d. upwards. Notwithstanding its application to pipe welds, it is also a very efficient radiographic machine. Mounted on a small stand it can be angled to all positions and, when removed from the stand, it can be put through small apertures.

Another new exhibit was the pipeliner spider illustrated. This machine traverses the bore of a pipe and examines the complete circumferential weld from the inside in one exposure. It is automatically adjustable for all pipe sizes from 6 to 18 in. i.d. When this machine has reached the root of the weld it is operated by remote control from the outside of the pipe.

Included in a comprehensive range of their latest welding equipment, electrodes, and accessories, the **Lincoln Electric Company Limited,** of Welwyn Garden City, Herts., exhibited a selection of motor generators and diesel welders, and their fully automatic " Lincolnweld " (illustrated).



A feature of Lincoln welders is the use of dual continuous control for both welding current and open-circuit voltage, the combination of these two controls permitting the operator to blanket the entire range of the welder. Similarly, by means of a " Job Selector," it is possible to select any size of welding arc merely by setting the Current Control for any desired amperage.

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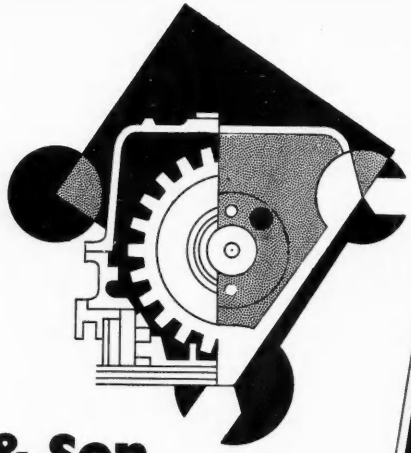

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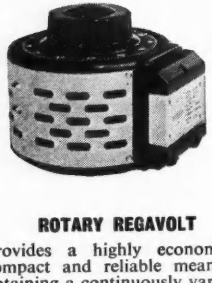

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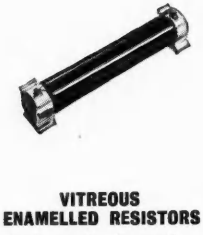

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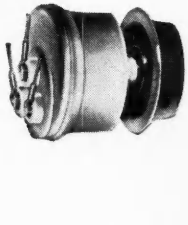

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NEWS OF THE MONTH

PERSONAL

Mr. Robert Atkinson, D.Sc., R.D., B.Sc., A.M.I.Mech.E., has been appointed director and general manager of Hamworthy Engineering Ltd. (Pump and Compressor Division), Fleets Corner, Poole, Dorset. **Mr. L. C. Baker, D.Sc., M.I.Mech.E.,** formerly chief superintendent engineer with Alfred Holt & Co. Ltd., has been appointed general manager of Hamworthy (B.C.E.) Ltd.

Group Captain B. H. Becker, A.F.R.Ae.S., R.A.F.(ret.), has been appointed technical manager, turbo-propellers, to D. Napier & Son Ltd., The Vale, London W.3. He will be responsible to **Mr. A. J. Penn,** chief engineer of the gas-turbine division.

Mr. Roy Burges has been appointed publicity manager of Birlec Ltd., Tyburn Road, Erdington, Birmingham 24, in succession to **Mr. J. C. Mantell, M.B.E.,** who remains, however, with the A.E.I. Group of Companies. He will take a training course with the British Thomson-Houston Co. Ltd., Rugby.

Mr. J. R. Condie has been appointed manager of the design department of F. Perkins Ltd., Peterborough. **Mr. J. G. Dawson, A.M.I.Mech.E.,** has been appointed manager of the experimental department, with **Mr. M. Vulliamy, M.A. (Cantab.), A.M.I.Mech.E.,** continuing as chief experimental engineer. **Mr. W. Spoor, A.M.I.Mech.E., A.M.I.Loco.E.,** has been appointed assistant to the director of the engineering division, **Mr. M. I. Prichard.**

Sir Charles Cunningham, C.S.I., F.I.G.M., chairman of the Greenwood Tea Co. Ltd., and **Mr. S. Collier, M.C., F.I.G.M.,** managing director of the Cleveland Petroleum Co. Ltd., have been elected to the Council of the Institute of General Manager, 86 Eccleston Square, London, S.W.1.

Mr. Gilbert Dodd, general manager of Monsanto Plastics Ltd., 8 Waterloo Place, London S.W.1, has been elected to the Board of the company.

Mr. Thomas G. Ellison has been elected chairman of George Ellison Ltd., Perry Barr, Birmingham 22 B, of Tufnol Ltd. and of Alfred Ellison Ltd., to succeed his father, the late **Mr. George Ellison,** whose death was recently announced. **Mr. George Ellison** and **Mr. John Ellison,** brothers of the new chairman, and **Mr. Arthur E. Skan** continue as directors of all three companies.

Mr. George E. Gamble, director of Wm. Whitehouse & Co. Ltd., Empire Works, Brueton Street, Birmingham 4, has retired after sixty-one years of service with the company. He is 81 years of age.

Mr. A. E. S. Gourlay, A.M.I.Mech.E., M.I.Mar.E., a director and general manager of Clews Petersen Ltd. for the past 16 years, has been appointed technical sales representative in Scotland for the Sheepbridge Group of Companies. He will operate from 46 Hazelwood Avenue, Newton Mearns, Renfrewshire.

Mr. Walter Grainger, M.Inst.F., and **Mr. John Mayer, B.Sc., A.M.I.Mech.E.,** have been appointed joint managing directors of International Combustion (Holdings) Ltd., 19 Woburn Place, London W.C.1. Both the new joint managing directors have been with International Combustion Ltd. for over 30 years.

Mr. W. H. Grinsted, O.B.E., has been appointed technical director of Siemens Brothers & Co. Ltd., Caxton House, London, S.W.1.

Mr. J. Kenneth Hampton has been appointed London representative of the Heath Spring & Notion Co. Ltd., Redditch, and will operate from 229 Grand Buildings, Trafalgar Square, London W.C.2.

Mr. H. E. G. Harvey, publicity manager and public relations officer of Ferodo Ltd., Chapel-en-le-Frith, for the past four years, has been appointed sales manager and deputy to the chief American executive of the newly formed British subsidiary of the Webster-Chicago Corporation.

Mr. William Holyoak has been appointed production manager of the Fort Dunlop factory of the Dunlop Rubber Co. Ltd., in succession to the late **Mr. T. S. Gardner.**

Mr. William Jeffers has been appointed chief docks manager, South Wales Docks, British Transport Commission, with headquarters at Cardiff, to succeed **Mr. A. E. H. Brown, T.D., M.Inst.T.,** who has been appointed general manager, Scottish Region, British Railways.

Mr. D. W. Mansell, vice-president of Brush Aboe Inc., New York, N.Y., has been appointed sales manager of The National Gas and Oil Engine Co. Ltd., Ashton-under-Lyne, and director of National Oil Engines (Export) Ltd. **Mr. A. A. King** succeeds Mr. Mansell as vice-president of Brush Aboe Inc. **Mr. F. D. Langley,** a director of National Oil Engines (Export) Ltd., has been appointed London manager. **Mr. D. M. Muirhead,** personal assistant to **Mr. M. C. Clear,** Group sales director, assumes Mr. King's responsibilities as Group sales representative in the Far East.

Mr. P. G. Masefield, M.A.(Eng.), C.I.Mech.E., F.R.Ae.S., F.I.Ae.S., M.Inst.T., has relinquished his position as chief executive of British European Airways Corporation to join the Bristol Aeroplane Co. Ltd. He has been appointed to be first managing director of the new subsidiary company, Bristol Aircraft Ltd.

Mr. Walter Meech has been appointed commodore chief engineer officer of the fleet of the British India Steam Navigation Co. Ltd., 122 Leadenhall Street, London E.C.3, in succession to **Mr. W. Johnson,** who has retired.

Mr. P. D. Osborn, B.Sc.(Eng.), A.M.I.E.E., has been appointed sales manager for fractional h.p. motors of Crompton Parkinson Ltd., Crompton House, Aldwych, London W.C.2, in succession to **Mr. R. V. Powditch, O.B.E., T.D., A.M.I.E.E., A.M.I.Tech.E.**

Mr. William Paynter, formerly production manager of the special products division of E. K. Cole Ltd., Southend, has been appointed works manager of Mervyn Instruments Ltd., St. John's, Woking, Surrey.

Mr. W. Plumb has been appointed deputy commercial manager for the Liverpool and Netherton Works of The English Electric Co. Ltd. **Mr. A. J. Evans** has been appointed to succeed Mr. Plumb as manager of the Leeds branch office.

Mr. H. V. Potter, chairman and managing director of Bakelite Ltd., 12 Grosvenor Gardens, London, S.W.1, is retiring from his position of managing director, but will continue as chairman of the company. **Mr. F. J. Robinson** will vacate his position of deputy managing director. **Mr. G. W. Hodds** has been appointed managing director as from 1st November, 1955.

Mr. C. M. Spielman, O.B.E., M.C., M.I.C.E., M.I.Struct.E., has been elected chairman of Whessoe Ltd., Darlington.

Mr. G. D. Toogood, A.M.I.Mech.E., general manager of Heat Exchangers Ltd., 53 Haymarket, London S.W.1, has been elected to the Board of the company.

Mr. E. Watt has been appointed branch manager in Chester for British Insulated Callender's Cables Ltd.

Mr. E. C. Whiteley, A.M.I.P.E., has been appointed manager of the Middle East Division of Metropolitan-Vickers Electrical Export Co. Ltd. He retains his responsibilities in connection with the petroleum industries, for which he has been the company's special representative since 1949.

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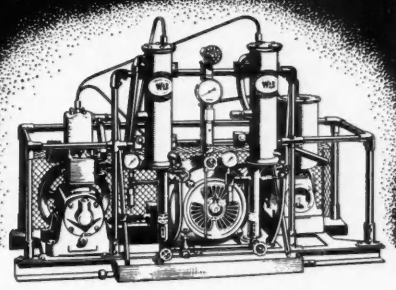
3" STROKE THREE STAGE

COMPRESSOR PLANTS



Delivery Pressure	2,000 lb/sq in	4,100 lb/sq in
Piston Displacement	9.8 cu ft/min	9.2 cu ft/min
Time taken to charge a 1 cu ft air bottle to maximum pressure	20 minutes	43 minutes

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- ★ Ample cooling without oil
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- ★ Robustly constructed in drip-proof sheet-metal housing of pleasing design

This plant, with a generous output range, is ideally suitable for general light, medium and heavy fabrications. It is equally good for all classes of maintenance and repair work.

Capacity is 60 to 350 amps, with infinitely variable current adjustment.

Electrodes 12 s.w.g. to 5/16 in.

The plant embodies the finest modern features of welding transformer construction.

Power Factor Correction

Power factor Correction Capacitors can be fitted if required (A 6KVA capacitor is the appropriate size for this equipment).

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FILTRATION EQUIPMENT · BATTERY CHARGERS AND RECTIFIERS · LAMPS AND LIGHTING EQUIPMENT · X-RAY EQUIPMENT

(P10004)

O.E.E.C. ENERGY COMMISSION

Sir Harold Hartley (United Kingdom), President of the World Power Conference since 1950, has been appointed Chairman of the newly constituted O.E.E.C. Commission for Energy. The other members will be:

M. Jacques Desrousseaux (France), Director of Mines;

Mr. H. D. Fransen (Sweden), Adviser on Energy to the Swedish Government;

Professor F. Giordani (Italy), Chairman of the Italian National Council for Nuclear Research;

M. N. Niesz (Switzerland), Industrialist and Chairman of the Swiss National Energy Committee;

Mr. G. A. Tuyl Schuitemaker (Netherlands), Technical Adviser to the Netherlands War Ministry; Vice Chairman of the Permanent Council of World Petroleum Congresses;

Dr. F. W. Ziervogel (Germany), Industrialist; President of the Essen Chamber of Commerce; an expert on coal gas production and coal utilization.

The eighth member of the Commission will be Monsieur Pierre Uri, who has been nominated by the High Authority of the European Coal and Steel Community, where he is Director of the Economic Division.

The Government of the United States has great interest in the work, and is to send an observer to the meetings of the Commission.

The members of the Commission have been chosen in a personal capacity by reason of their knowledge of the general problem of energy and of their personal standing in the Organization or in their respective countries.

The duty of the Commission is:

(*a*) to collect and collate all useful information concerning the requirements and resources of the Member countries in all forms of energy, both in the recent past and, wherever possible, in the years to come;

(*b*) to examine the chief problems, in particular the economic and financial problems, which may arise for Member countries in this respect, and to compare the methods that Member countries employ or expect to employ to resolve them; and

(*c*) to formulate proposals for finding still better solutions for these problems by means of co-operation within the Organization.

The Commission will not deal with questions relating to the use of nuclear power until the O.E.E.C. Council so decides in the light of the report of an O.E.E.C. Working Party on nuclear energy set up on 10th June.

The Commission is expected to start its work in September, and will submit a report to the Council of O.E.E.C. before 1st March, 1956.

FIFTH ELECTRICAL ENGINEERS EXHIBITION

Final arrangements are now being made for the next Electrical Engineers Exhibition (sponsored by the Association of Supervising Electrical Engineers) which will again be held at Earls Court, London, from March 20th to 24th, 1956.

The following principal organizations will support the Exhibition:—

The Association of Supervising Electrical Engineers; The British Electrical and Allied Industries Research Association; The British Electrical Development Association; The Cable Makers Association; The Central Electricity Authority; The Electrical Association for Women; The Electrical Industries Benevolent Association; The Electrical Wholesalers Federation; and, for the first time, the British Standards Institution will be exhibiting.

Over 30 stands will cover an area of 1000 square feet each and some will be over this size. The Exhibition will again be the largest Electrical Exhibition ever held in this country, and possibly in the world.

"MATERIAL UTILISATION"

A Report under this title has been produced by a Sub-Committee of the Institution of Production Engineers' Research Committee and is now available from the Institution's Head Office at 5/- per copy, post free.

The Sub-Committee was set up to investigate the extent to which British industry is making the best use of materials, to discover what proportion is converted into useful products, and to see if ways can be found to increase that proportion.

In this first Report, the Sub-Committee has confined its investigation to the metal working industries and to metal working. The Report is based on a large number of case studies which were collected from industry, mostly with the help of Working Parties set up by various Sections of the Institution; it is set out in three main sections—(*a*) a general survey of the present position; (*b*) a large number of illustrated case studies; (*c*) conclusions and recommendations.

The aim of the Sub-Committee has been to provide a publication of direct use to the production engineer, with the information set out in a brief and easily digested form. It is the belief of the Sub-Committee that much can be done by industry to improve the effective utilization of material, and an examination of this Report should give food for thought.

"THE IMPACT OF SCIENCE ON MANAGEMENT IN THE FUTURE"

The National Conference of the British Institute of Management will this year be held at Harrogate from 2nd to 4th November, 1955. Speakers who have already accepted invitations to address the conference include John Diebold, American pioneer of the application of "automation," Sir Geoffrey Vickers, V.C., and Sir Charles Goodeve, O.B.E., F.R.S., director of the British Iron and Steel Research Association.

Provision is being made for 1000 top managers to be received at Harrogate as delegates to the conference and a programme is being prepared which will include two plenary sessions and twenty-four sectional meetings devoted to specialized aspects of management.

So fundamental are the changes with which the scientists are confronting industry at the moment that many people are already talking in terms of a second industrial revolution. At the same time it is obvious that the face of Britain cannot be transformed overnight. The discoveries of the scientist must be translated into the practice of everyday living. The responsibility for transferring new knowledge from the research laboratory to the production floor must rest with management.

"SILICONES FOR INDUSTRY" EXHIBITION

An exhibition on the history, production and application of silicones is to be held in Leeds in the Large Hall, Leeds Church Institute, 5 Albion Place, from Monday, September 26th, to Friday, September 30th.

The exhibition will be open each day from 10.00 a.m. until 6.00 p.m. with the exception of Monday (opens 2.30 p.m.). There are many working exhibits. Film shows will be given at intervals throughout each day.

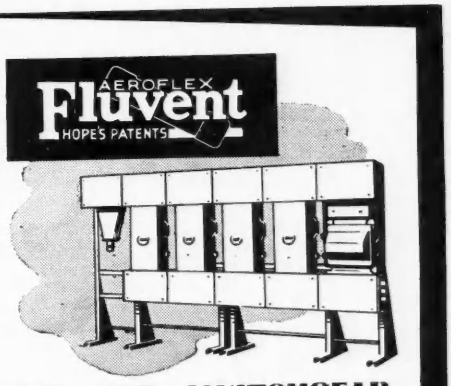
Invitations to the exhibition can be obtained on request from Midland Silicones Limited, 19 Upper Brook Street, London W.1.

CONFERENCE ON STEELWORKS CRANES

A conference on E.O.T. Cranes organized by the Plant Engineering Division of the British Iron and Steel Research Association will be held at the Hotel Majestic, Harrogate, on October 5th and 6th, 1955, under the Chairmanship of Mr. W. F. Cartwright, D.L., J.P., M.I.Mech.E., assistant managing director and general manager (Steel Division) of the Steel Company of Wales Ltd.

Papers on steelworks requirements for cranes; manufacturers' views; structural design; mechanical features—bearings, couplings, rail wheels, etc.; crane cab layout and design of controllers; electrical equipment and safety aspects of crane design, operation and maintenance, will be presented by representatives of the iron and steel industry, crane and electrical equipment manufacturers, H.M. Inspectorate of Factories, and BISRA.

Although much of the conference will be specifically related to the electric overhead travelling type of crane, other aspects of the subject, such as studies of cab and control design and the techniques



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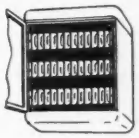
—range from the industrial switchboard to the domestic House-Service cut-out; new—the Cabinet Style Board.



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The days when one could write 'firebrick' on the drawings for a furnace, and leave it at that, are over. Higher temperatures, higher outputs, more stringent demands all round, have resulted in the development of a great complexity of new refractory materials. Except in the simplest of applications, only a specialist can now be quite sure of the best refractory for the job.

You find some of the most experienced of such specialists at Morgan Refractories. Their advice and collaboration is yours for the asking. They have themselves been responsible for the development of some of the finest refractories ever made. They operate the most up-to-date refractories plant in Europe. Their advice is worth having.

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of stress measurement, will have a much wider application. An account of the research on cranes carried out by BISRA is contained in "BISRA SUMMARY No. 77," a copy of which is available on application to the Information Section, The British Iron and Steel Research Association, 11 Park Lane, London, W.1.

The specification for heavy duty E.O.T. cranes for use in iron and steel works has also been revised in the light of this research. Copies of the revised specification will be available prior to the conference. (Charge to non-members 10/-.)

Full particulars of the conference may be obtained from the Technical Secretary, Plant Engineering Division, The British Iron and Steel Research Association, 140 Battersea Park Road, London, S.W.11.

BRITISH NUCLEAR ENERGY CONFERENCE

The first meeting of the British Nuclear Energy Conference will be held at the Institution of Civil Engineers, Great George-street, London, S.W.1, on Wednesday, November 30th, 1955.

The meeting will be opened by the chairman of the Conference, Sir Christopher Hinton, M.A., F.R.S., M.I.Mech.E., and four lectures will be delivered, comprising: "The United Kingdom Atomic Energy Project," by Sir John Cockroft, K.C.B., Hon. M.I.Mech.E., F.R.S.; "The Place of Nuclear Energy in United Kingdom Power Development," by Mr. V. A. Pask, C.B.E., M.I.Mech.E., M.I.E.E., and Mr. J. C. Duckworth, B.A.; "The Use of Research Reactors in Nuclear Power Development," by Mr. H. J. Grout, B.Sc., A.M.I.Mech.E.; and "Health and Safety in Nuclear Power Industry," by Dr. A. S. McLean, M.B., Ch.B., D.I.H., and Dr. W. H. Marley, M.Sc.

Owing to the limited accommodation available, attendance at the symposium will be restricted to members of the five institutions participating in the Conference and members are asked to apply to the secretaries of their respective institutions as promptly as possible. Advance copies of the lectures will not be available.

The secretary of the Conference is Mr. A. McDonald, 1-7 Great George-street, London, S.W.1.

BUSINESS NOTES

Rapid Magnetic Machines Ltd., Lombard Street, Birmingham 12, announce that they have been sole licensees for the Crockett heavy media separators for many years and that they co-operate with Dings of U.S.A. in this field. They have no connection with any other concern purporting to manufacture "Crockett Type" Separators.

British Insulated Callender's Cables Ltd. announce that the telephone number of their London branch sales office at 10/14 White Lion Street, N.1, is now TERminus 2701.

Acorn Spring Works Ltd. have closed down their factory in London and have moved their works and offices to a newly built factory at Poyle Trading Estate, Colnbrook, near Slough, Bucks. Tel. No.: Colnbrook 464.

Wickman Ltd., Tile Hill, Coventry, have assumed the sole agency for the whole range of surface grinding machines, automatic horizontal rotary grinding machines, centreless grinding and piston grinding machines, special purpose grinding machines and profile turning lathes manufactured by Arthur Scrivener Ltd., Tyburn Road, Birmingham.

Heenan & Froude Ltd., Worcester, announce that their telephone number is now Worcester 3461 (10 lines).

The Power Gas Corporation Ltd., Stockton-on-Tees, with subsidiaries in Hull, Johannesburg, Melbourne, Paris, Montreal and Calcutta, and offices in London and Bombay, have established five specialized divisions. The new divisions and their respective heads are:—Works Division—Mr. T. K. Hargreaves, director; General Contracts Division—Mr. C. Ingman, divisional director; Gas Plant Division—Mr. T. H. Riley, divisional director; Chemical Plant Division—Mr. P. M. K. Embling, divisional manager; Blast Furnace Division—Mr. D. R. Brown, divisional manager.

The Lockheed Hydraulic Brake Co. Ltd. and the **Borg & Beck Co. Ltd.,** of Leamington Spa, will shortly extend their manufacturing activities to India. They have granted manufacturing and selling licences to Automobile Products of India Ltd., in Bhandup, Bombay. In the initial stages this company will receive from Britain component parts of automobile accessories to be assembled in the Union. The manufacture of these parts in India will gradually increase until complete units will be of Indian manufacture.

The Technical Survey, published twice a year by the Copper Development Association, gives a comprehensive review of recent technical developments in the production, properties and applications of copper and its alloys, with an extremely useful bibliography.

A copy will be sent free to any reader who makes a personal application to the Copper Development Association at Kendals Hall, Radlett, Herts, with a request to be placed on the mailing list for future issues.

George Ellison Ltd. and **Tufnol Ltd.** announce that in future the sales and engineering service for "Ellison" electric switchgear and "Tufnol" in Canada will be handled by the Electric Construction Co. Canada Ltd., 1947 Avenue Road, Toronto 12.

The president and managing director of Electric Construction Co. Canada Ltd. is Mr. H. Copping, M.I.E.E., who was associated with George Ellison Limited for 25 years.

The Birmingham Small Arms Company Ltd. is to establish a manufacturing unit in Northern Ireland. A Government factory at Carnmoney, near Belfast, is being extended to suit the requirements of the firm. The immediate intention is to build up a labour force of approximately 500-600 workers of whom 60 per cent will be male.

The firm will partly manufacture a portion of their Government contract work in the new factory and will investigate the possibility of including civilian work.

Birmingham Sound Reproducers Ltd. are to take over the Northern Ireland Ministry of Commerce advance factory at Pennyburn, Londonderry, which at present is in course of erection. The factory has been designed for the accommodation of about 200 workers and is expected to be completed early in 1956.

Birmingham Sound Reproducers Ltd. first commenced production in Northern Ireland in June, 1951, and employ more than 900 men in their Blighs Lane factory.

The Ministry understand that Birmingham Sound Reproducers Ltd. intend to erect a 50,000 square feet factory at Drumahoe on the outskirts of Londonderry. It is planned to have this building ready for occupation by the summer of 1956. The company intends to manufacture light engineering products at both Pennyburn and Drumahoe.

D. Napier & Son Limited of Acton, London, and Power Generators Incorporated of Trenton, New Jersey, have concluded an agreement granting Power Generators rights to manufacture and market the Napier "Spraymat" electrical de-icing system. The area specifically allotted includes all the Eastern States in the U.S.A.

The Napier "Spraymat" system has recently been successfully tested under United States Air Force auspices at the Mount Washington Climatic Testing Facility, New Hampshire. A new technical brochure containing results of these and other tests is being made available to the aircraft industry with the co-operation of the U.S.A.F.

Metal Industries Ltd., Universal House, 60 Buckingham Palace Road, London S.W.1, announce the addition to their telephone lines and change in numbers: SLOane 5587 superseded by SLOane 7192, 7193 and 7194, SLOane 5814 and 5618 remain in service.

Sheppard & Sons Ltd., Bridgend, Glamorgan, have completed an agreement with the Consolidated Mining and Smelting Company of Canada Ltd., Trail, B.C., Canada, for the manufacture and supply of molten metal pumping equipment. The pump, recently developed in Canada, takes the form of a unit submerged into the main body of the metal, and in its present form is capable of a lift of up to 26 in. with a pumping rate of 290 lb of metal per minute, or more than 200 tons in 24 hours. The pump can be used also for aluminium and other non-ferrous metals.

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POSITIVE LOCK WASHERS

Nuts and bolts stay firmly in place, are unaffected by vibration, when a KOLOK Positive Lock Washer is fitted between them. Available in all sizes.

POSITIVE LOCK WASHER CO LTD.,
45 RENFREW ST., GLASGOW C.2. DOUglas 9292

THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

Industrial Group Headquarters,
Risley, Nr. Warrington,
invites applications for the post of

SENIOR LABOUR MANAGER
ON
CONSTRUCTION WORKS

Applicants must be fully conversant with all negotiating machinery, and have had experience in handling constructional labour and dealing with Trade Unions on such matters as conditions of work, rates of pay, etc., for Building, Civil, Mechanical and Electrical Labour. The successful applicant will be required to deal with all labour matters on several large construction sites in various parts of the country, and be responsible to the Chief Engineer (Construction).

Salary—£1,160 to £1,370 per annum.

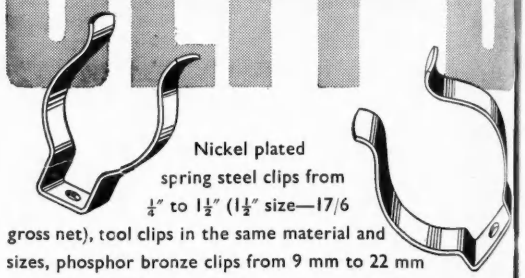
Housing accommodation will be available within a reasonable time for the successful candidate, if married; hostel accommodation is also available.

All new entrants under the age of 55 automatically join the Authority's contributory pension scheme.

Send postcard for Application Form to Senior Recruitment Officer, U.K.A.E.A. Industrial Group H.Q., Risley, Nr. Warrington, quoting reference 1,076.

CLIPS

SPRING STEEL
PHOSPHOR BRONZE



Nickel plated spring steel clips from ¼" to 1½" (1½" size—17/6 gross net), tool clips in the same material and sizes, phosphor bronze clips from 9 mm to 22 mm —say when! There are lots of variations on the same theme and if it isn't in stock we can soon make it. Better get in touch with Lewis of Redditch today.

LEAVE IT TO Lewis OF REDDITCH
SPRINGS, SPRING CLIPS
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To help your design department, The Lewis Spring Company offer a 40-page booklet on spring design, full of technical data. 2/6d. post free.

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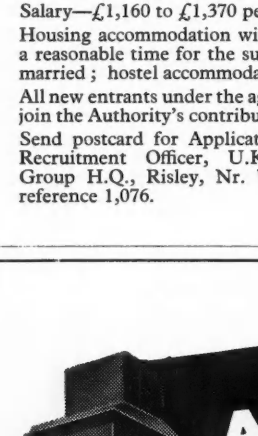

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COOLING TOWERS

Are YOU letting costly WATER run to waste?

●Let us advise on your heat, water and dust extraction problems, etc.

STUDY your works water bills! You can save up to 97% of costly cooling water with Midland Aquamisers. In many cases such installations pay for themselves in the first year when used for Air Compressors, Diesel Engine Cooling, Heat Exchangers and similar operations. Furthermore the Midland Aquamiser, used in conjunction with water chilling plant, can result in improved manufacturing precision in such operations as high speed screwing and certain grinding operations, and the cooling of plastic presses. Write for interesting Midland Heating & Ventilation Co. Ltd. brochures on the Midland Aquamiser, Space Heating, Dust Collection, Fume Extraction, etc.

MIDLAND HEATING & VENTILATION CO. LTD.
BEDFORD RD. BIRMINGHAM. 11.
PHONE: VICtoria 0914-5

Tacol Ltd., formed last year by Mr. Charles J. Wright, a consulting engineer specializing in oil refinery projects, of Ockley, Surrey, has been appointed by the Government of Iraq as adviser in the country's refinery development programme.

CONTRACTS

The Butterley Company Ltd. announce a further contract for a large oxygen/nitrogen plant to be installed at the Billingham Division of Imperial Chemical Industries Ltd. This plant will produce 240 tons of high purity oxygen and 400 tons of very high purity nitrogen per day.

In addition to the above, contracts already in hand include a 200 ton per day very high purity oxygen plant for Stewarts & Lloyds Ltd. for their Corby works.

Contracts for smaller plants have also been secured from The Newport Division of The Steel Company of Wales Ltd. and British Celanese Ltd. Orders secured to date for various types of oxygen/nitrogen plants are now valued at considerably more than one million pounds.

W. G. Bagnall Ltd. of Stafford have received a contract from the New Zealand Government Railways for the supply of seven 0-4-0 diesel-mechanical shunting locomotives.

Two of the locomotives will be powered with Gardner 6L3 engines and the remainder with McLaren M6 engines. The nominal horsepower will be 150 and the weight in working order, 20 tons. The transmission will consist of a Fluidrive hydraulic coupling and four-speed gear box (type S.E.4) and a reverse and final drive box (type R.F.11) which will be supplied by the Self Changing Gear Company. The drive to the wheels will be by coupling rods from fly-cranks keyed to the output shaft of the reverse and final drive box.

This order follows a contract from New Zealand placed for ten 240 hp 0-6-0 diesel shunters, powered by National M4AA6 engines, which are now under construction at Castle Engine Works.

The General Electric Co. Ltd. has been entrusted by The Australian Iron and Steel Co. Ltd. with a contract valued at £165,000 covering the complete electrical equipment for a 2-stand temper mill for steel strip at Port Kembla, New South Wales. The mill will be similar in design to those now in commission at the Trostre Works of The Steel Company of Wales, which were the first in Great Britain to operate at strip speeds of up to 4,000 ft per min.

Each stand of the mill will be driven by a 1,000 hp d.c. motor, and six motors totalling 2100 hp are included for the auxiliary drives. G.E.C. control exciters operating in conjunction with a Ward Leonard system will be used to provide the rapid response and complete stability which are essential features of a control scheme for high-speed mills of this type.

The contract is the latest of a series of orders placed with the G.E.C. for equipment for the Australian Iron and Steel Company's Works at Port Kembla; they include main and auxiliary mill motors, mercury arc rectifiers, switchboards and control gear.

The English Electric Company Ltd. have received, through the Crown Agents, an order for the Malayan Railways covering twenty main-line 1500 hp diesel-electric locomotives. The value of the contract is approximately £1½ million. The locomotives will haul express trains, up to 450 tons in weight, on the Singapore—Kuala Lumpur—Prai Line. They weigh 96 tons each and are of the Co-Co type, embodying the English Electric 12SVT diesel engine, which is rated at 1500 hp, 850 rpm.

The Malayan Railways are planning extensive improvements to their main-line services. The operating speed at the moment is limited to 45 mpn; with the new locomotives a maximum speed of 60 mph will be possible.

Further information is now available on the order which the company received earlier this year from the Indian Railway Board. The contract covers twelve 3000 volt, 3120 hp direct current electric locomotives of the Co-Co type—each weighing 111 tons—the total value being approximately £800,000. The locomotives are generally similar to the seven 3600 hp 1500 volt English Electric locomotives which went into service earlier this year on the Central Railway, India, operating from Bombay. The twelve additional locomotives will operate on the Howrah-Burdwan section of the Eastern Railway, Calcutta area, where the Indian Railway Board have planned a very extensive 3000 volt electrification. *They will be the first 3000 volt electric locomotives to operate in India.*

Aluminium Wire & Cable Co. Ltd. have received an extension of their previous order from the British Columbia Electric Railway Co. Ltd. for the supply of "Drake" steel-cored aluminium conductor. A further 700,000 lb will be delivered in Vancouver by February 1956.

The Loewy Engineering Company Ltd. has secured against international competition an order from the important Steelworks of Ilva for a Continuous Medium Strip Mill worth more than £½m. and to be delivered end 1956.

The plant is similar but somewhat smaller in size than the Continuous Strip Mill which, as recently announced, is being built by The Loewy Engineering Company Ltd. for Steel, Peech & Tozer, a Branch of The United Steel Companies Ltd.

Both mills will have a very high output of steel strip to meet the growing demand for a number of engineering and domestic uses.

ERRATUM

Two rather serious typographical errors have appeared in the August advertisement of the Electro-Dynamic Construction Co., Ltd. The final paragraph of copy refers to a "Voltage controlled by automatic regulator within plus or minus 2%." This should read, "Plus or minus 1%." The advertisement also refers to the Frequency being stabilised by electronic Servo Regulator within plus or minus 5%. This should read, "Plus or minus 0·1%."

Classified Advertisements

The rate for all classified advertisements is 6d. per word; in bold print 9d. per word; minimum order 6s. Box-number advertisements 1s. extra. Instructions, together with remittance, must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

EVERY APPROVED CANDIDATE graded in Engineering and Allied Classes (Administrative, Executive or Technical) is eligible for membership of the Institute of Executive Engineers and Officers. Service to members for an annual subscription of Four Guineas (Fellow)—(35 years), Three Guineas (Member)—(30 years), Two Guineas (Associate)—(25 to 35 years of age), includes: Advice and information—Quarterly Journal—Publication of Members' Papers—Gold and Silver Medal Awards—Frequent News Letters—Latest Literature—Technical Library Accessions—Lectures—Income Tax and National Insurance Queries—Legal Advice—Journal Notices—Appointments Register for Members and Firms, etc. Enjoy these valuable services and Professional status. For application form and examination exemption particulars give age, training, appointment held and industry, government or municipal department to:—

The Secretary, Executive Chambers,
241, Bristol Road, Birmingham, 5

SITUATIONS VACANT

Imperial Chemical Industries Ltd., Metals Division, require an **ELECTRICAL MAINTENANCE ENGINEER** for their works in South Wales.

Candidates should possess at least Higher National Certificate in Electrical Engineering or equivalent and experience with modern Rolling Mill Electrical Equipment, electric furnaces, instruments and ancillary plant desirable. Application forms to be obtained from **Staff Manager, Metals Division, Kynoch Works, Witton, Birmingham, 6,** quoting reference ENG/246.

Imperial Chemical Industries Ltd., Metals Division, have vacancies for **MECHANICAL AND ELECTRICAL ENGINEERS** in the following fields:—

(A) Rolling Mills, Extrusion Presses and heavy metal production plant.
(B) Materials Handling and Mechanisation.
(C) Intricate special purpose machines for fabrication of small metal components.
(D) Steam, Water, Gas and Air distribution schemes. Heating and Ventilating and Air Conditioning Plant.
(E) Furnaces of all types in connection with Metal Production.

Technical qualifications of Engineering degree, Higher National Certificate and/or Associate Membership of Institution of Mechanical or Electrical Engineers desirable. Applications for form should be addressed to **Staff Manager, Kynoch Works, Witton, Birmingham, 6,** quoting Ref. ENG/GEN.2.

NON-FERROUS FOUNDRY MANAGER (Directorship later) required, preferably experienced technically and commercially in centrifugal casting. Exceptional remuneration and an interest in financial results. Apply in confidence, Chairman, **Metals & Alloys Ltd., Minworth, Birmingham.**

Imperial Chemical Industries Ltd., Metals Division, invites applications from suitably qualified

ENGINEERS and PHYSICISTS

to fill the following permanent positions in its

RESEARCH DEPARTMENT

(1) **A MECHANICAL ENGINEER** is required to take charge of a section engaged on engineering research activities covering the investigation of metal fabrication processes and the development of special machines and instruments.

(2) **An ENGINEER** or a **PHYSICIST** is required to build up and subsequently to lead a new section to study the plastic deformation of metals principally as encountered in manufacturing operations.

Candidates should preferably be not more than 35 years of age, should possess either a first or second class honours degree of a recognised university or an equivalent qualification, and should have had experience in research and/or development work.

Commencing salary will be in accordance with age, qualifications, and experience, but in any event will be of the order of £1,335 p.a., and there are good prospects of advancement.

Financial assistance towards removal expenses are available for married men. Excellent conditions of employment include Staff Pension Fund, Employees' Profit Sharing Scheme, etc.

Application forms may be obtained from Staff Manager, **I.C.I. Metals Division, Kynoch Works, Witton, Birmingham,6,** quoting RES/5.

BEARINGS

BALL & ROLLER BEARINGS.—All Types and Sizes, Largest Stocks, Lowest Prices. Same day dispatch. **895-921 Fulham Rd., London, S.W.6.** Renown 6174 (Ext. 24).

LATEST INDUSTRIAL LITERATURE

1. Automatic Shut-Off Valve. Details are contained in a well-produced and illustrated 8-page brochure of an automatic shut-off valve intended for incorporation into the main gas supply to gas-burning appliances. The device consists of a pilot burner heating a thermocouple element, thereby generating a small electric current, which holds open the main valve by means of an electromagnet. Consequently, should the pilot burner go out for any reason, the main valve will shut within a short time and will remain shut until the device is manually reset and the pilot re-ignited.

This valve can be used on all gases and on all sizes and types of gas appliances.

2. Tubular Heat Exchangers. Produced by a firm who have specialized in the manufacture of steel tubes and fittings, tubular fabrications, manipulated pipework, drop forgings, and heat-transfer equipment, a range of tubular heat exchangers is described and illustrated in an excellently produced 24-page booklet.

In the design of these exchangers, the main object has been to produce equipment capable of transferring the specified amount of heat, under specific operating conditions, in the minimum space and with the minimum pressure drop.

3. Mercury-Arc Rectifiers. In a well-produced and illustrated 28-page brochure, details are given of a wide range of mercury-arc rectifiers which can be supplied in sizes of one or two kilowatts up to any required capacity, the design varying according to capacity and application. The smaller types of equipment up to 20 or 30 kW are mounted in cubicles, the transformer being housed in the base of the cubicle, so that the rectifier equipment is completely self-contained. For higher capacities, a different type of cubicle is employed, this being designed to stand next to a small oil-cooled transformer.

Illustrations and details of a complete range of standard rectifier units, together with associated transformer weights and measurements, are also included.

4. Projector and Photographic Lamps. Issued by a firm with very many years of experience in the manufacture of both projectors and projector lamps, an interesting, illustrated 26-page catalogue lists and describes an extremely wide range of projector and photographic lamps for many purposes. Projector lamps include those suitable for motion-picture projection, for micro-projection, for hospital theatres, and for tubular and theatre spotlights, while photographic lamps include flood, enlarger, and studio lamps, as well as mercury-vapour, xenon electronic flash, and photoflash lamps.

The catalogue includes comprehensive illustrated details of a wide range of lamp caps and filaments, together with details of recommended projection lamps for practically every make of motion-picture projector.

5. Safety System for use with Portable Electric Tools. Details are contained in an illustrated pamphlet of a safety system for use with portable electric tools. By means of this system it is possible to cover a number of low-voltage points with a minimum of portable-tool transformers, thus enabling the maximum of safety to be obtained with a minimum of outlay, as all that is necessary is to fit an additional special plug box in position whenever it is required to use a portable tool for the first time.

Once fitted and earthed, these plug boxes are left permanently installed, ready for use at any time. It is thus unnecessary to wire a building throughout with a low-voltage system.

6. Electromagnetic Clutch and Brake Units. Details and prices are given in an illustrated 4-page brochure of a range of electromagnetic units which meet the need for compact, high-efficiency transmission couplings. These units are suitable for the control of machine tools and other power drives, as well as the remote control of change-speed and reversing gearboxes. They are of high torque capacity, with low current consumption ; furthermore, no periodic manual adjustment is required at any time, and there is no gap to be maintained. Single units are made up of only three component parts, and double units of five component parts.

The range comprises sizes with magnet diameters ranging from 2⅜ to 9 in., and all industrial units have 24 V d.c. windings, thus making them quite free from the danger of any high-voltage leakage. Where direct current is not available, a standard range of mains/transformer/rectifier units is available for all models.

MAIL THIS COUPON TO-DAY

THE ENGINEERS' DIGEST, 9.55
120, Wigmore Street, London, W.1.

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Please send free and without obligation the literature indicated by the following circled numbers :

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Name .....

Position .....

Company .....

Address.....

BOOKS RECEIVED

Principles of Electric Utility Engineering. By Charles A. Powel. 259 pp., 105 illustrations. Publishers : The Technology Press of The Massachusetts Institute of Technology and John Wiley & Sons, Inc., New York, and Chapman & Hall Ltd., 37 Essex Street, London, W.C.2. Price : 48/-.

This book deals with the essentials of electric utility engineering —a tremendous and complex field—and opens the door to the every-day problems facing the engineer in all branches of the industry. It is the only book of its kind covering the essentials of the subject in one volume and, as such, the author has selected, on the basis of long experience, those problems which he has found basic to design and operation, presenting them in a framework of engineering philosophy and discussing the long-established principles behind the problems. The text of this book is essentially the notes which formed the basis of his lectures in engineering at The Massachusetts Institute of Technology.

Included in his picture of the industry is a general introduction explaining the corporate structure of the typical utility, definitions used in business, federal and state controls to which it is subject, and the financial return to be expected with given rates.

Electrical Measurements and Measuring Instruments. 4th Edition, 1955. By E. W. Golding, M.Sc.Tech., M.I.E.E., Mem. A.I.E.E. 927 pp., 550 illustrations. Publishers :—Sir Isaac Pitman & Sons, Ltd., Parker Street, Kingsway, London, W.C.2. Price : 40/-.

In this new and revised edition of this well-known work, symbols and nomenclature have been changed throughout, to conform with the most recent recommendations of the responsible committees, even though the resulting formulae may now seem to have a strangely unfamiliar appearance. The subjects of M.K.S. units and rationalization have been covered much more fully than in the previous edition, and the basic equations derived in Chapter I have been given in both unrationalized and rationalized forms. In this connection, however, the author feels that the present is a transitional period between that when C.G.S. units held sway and the period in the future when the M.K.S. rationalized system may be universally adopted. He has therefore attempted to carry along both systems, except where this would obviously cause confusion. For this reason, and also because of the abandonment of the International units in 1948, Chapter II has been altered considerably.

In the chapters concerned with measuring instruments, there have been many changes, to include newly developed instruments and to illustrate the latest forms of older instruments ; however, bearing in mind the essential function of the book as a text for students, descriptions of a few instruments now little used have been retained, when their operating principles have been considered sufficiently important. In addition, as a result of the introduction of new measuring techniques based on recent developments in electronics, a new chapter on " Electronics and Electronic Measuring Devices " has been included.

The book, one in the " Engineering Degree Series," covers the syllabuses of the B.Sc. Engineering, the City and Guilds (Final), and the I.E.E. examinations in this subject.

Nomography and Empirical Equations. By Dale S. Davis. 242 pp., 74 illustrations. Publishers : Reinhold Publishing Corporation, 430 Park Avenue, New York 22, and Chapman & Hall Ltd., 37 Essex Street, London, W.C.2. Price : 54/-.

In the preparation of this book, two major objectives have been achieved, i.e., the presentation of an easily understood treatment of the correlation of two- and three-variable data, and the provision of minimum but adequate theory, detailed working directions, and practical illustrations in connection with the design and construction of elementary alignment and line co-ordinate charts.

Part I of this useful book explains the development of empirical equations for two- and three-variable data. Here, new techniques utilizing trigonometric and hyperbolic functions, the modified Compertz equation, and other devices for two-variable data are described, together with simple methods of correlating three-variable data. Part II covers the theory and construction of several industrially important types of alignment and line co-ordinate charts, the step-by-step construction of which is shown by numerous illustrations, together with indications of their value and use in correlating data rapidly, simply, and accurately.

" Machinery's " Screw Thread Book. 16th Edition, 1955. 224 pp., 38 illustrations. Publishers : The Machinery Publishing Co., Ltd., National House, West Street, Brighton 1. Price : 10/-.

Ever since it first appeared in 1915, this useful book has been regarded as an authoritative reference work on screw threads. As more and more detailed information is being required by industry, especially for American screw threads, this new edition has been entirely rewritten. Furthermore, as published standards do not always cover the whole range of screw threads in use, an effort has been made to remedy this deficiency.

This book covers all important modern screw-thread systems, including British, American, German, French, and Swiss standard practice. Amongst the threads covered are Acme, Buttress, B.A., B.S.F., B.S.P., B.S.W., Conduit, Cordeaux, Edison, bottle-closure, well-casing, horological, and optical threads, as well as the new unified system and the American National threads. Precision gauging by wires is comprehensively covered, with newly calculated tables of constants, while accepted tolerance systems are given, together with a full-range progressive table of drill sizes.

THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *FLAME-SPRAYED CERAMIC COATINGS*

It is reported that ceramic coatings consisting of pure metal oxides can now be applied to metal and other types of surfaces by flame spraying. Expecially important appears to be the claim that these coatings do not require subsequent firing or baking and that they will withstand temperatures up to some 3000 F and erosion by gases at supersonic velocities. The coatings are said to be hard, wear-resistant, and to have low thermal conductivity. Coatings of aluminium and zirconium have so far received preferential attention, but the process can also be carried out to produce coatings of titania, mullite, and porcelain. Prior to the development of flame-sprayed ceramic coatings, the flame-spray technique was limited to applying metal and cermet coatings. The technique of flame-spraying ceramic coatings is essentially the same as conventional metallizing, i.e., the ceramic material is melted in a flame gun and sprayed with an air blast onto the surface to be coated. As the ceramic particles are in a semi-molten condition when they impinge on the surface, the base material must be able to withstand temperatures of only 600 to 800 F. Materials which have been successfully coated with alumina include ferrous and non-ferrous metals, ceramics, graphite-carbon, glass, and some types of plastics. With regard to the coating of curved or tubular surfaces, the fact that ceramics are brittle materials must not be overlooked. The compressive strength of these ceramics amounts to about ten times their tensile strength. It is not surprising, therefore, that a ceramic coating on a concave surface, such as the inside wall of a tube, will withstand many more cycles of heating and cooling than will a coating on the outside of the tube. It is reported that aluminium oxide coatings can be applied in thicknesses from 0·005 to 0·05 in.

● *INFLUENCE OF TAP-DRILL SIZE UPON THE STRENGTH OF TAPPED HOLES*

The influence of tap-drill size (minor diameter) upon the strength of threaded assemblies has been the subject of much speculation, analysis, and testing, but the results presented generally have been inconclusive or have not covered all the many possible types of thread failure. Failures can be of three types, i.e., stripping of the external-thread member, breaking of the external-thread member, or stripping of the internal thread. A recent research report gives the results of a series of correlative tests made in an attempt to solve this problem. The tests were conducted on external-threaded members made of hardened high-speed steel, hardened steel, and soft steel, while the internal threads were made of hardened steel, soft steel, and grey cast iron. In preparing the internal-thread speciments, special care was taken to ensure squareness. The surfaces were ground parallel, the holes were drilled and reamed carefully to size, and the threads were tapped on a leadscrew tapper. The external-thread specimens were made with ground major diameters and ground threads. The investigation showed that, for threaded assemblies of normal proportions, maximum strength is developed with 50% thread height and that exact tap-drill size is relatively unimportant, provided that the percentage of thread height is greater than 60%. However, tapping costs are likely to be lower if the lowest possible percentage of thread height is used. For exceptionally short lengths of engagement, or when less than 50% thread height is used, the minor-diameter size has a significant effect on assembly strength, and precision hole-sizing methods should be used. The report points out that these findings are based upon static loading and should not be applied indiscriminately to assemblies subject to severe vibration.

● *VACUUM-LAMINATING OF SILICONE-GLASS PARTS*

Vacuum-laminating, which is also known as " contact," " bag," or " extremely low-pressure " laminating, is a long and fairly complicated process as compared with matched die moulding. On a unit-cost basis, it is much more expensive than matched die moulding for long production runs. The method does, however, give the possibility of obtaining a small quantity of parts which are indistinguishable from parts made in matched die presses, and their cost of production is a fraction of that of a single steel mould. As a result, vacuum-laminating is becoming an increasingly popular method of producing a small number of experimental parts without the expense of production moulds. Vacuum-laminating is usually associated with the use of polyesters but, according to a recent report, excellent glass-reinforced laminates for high-temperature service can be made with certain silicone resins by taking into consideration a few basic differences in laminating properties. Unlike solvent-free polyesters, sili-

Meet Perishin' Fred!

Very fond of a grouse is Fred. Doesn't have to look far either. 'Like the perishin' North Pole in this perishin' factory', growls Fred. But at least he stays on the job; half the girls are away with the sniffles.

Now meet Bert — of the boiler'ouse

'It's no good them coming grousing to me,' glowers Bert, 'radiators are full on (or nearly), and the Guvnor's always bitin' my 'ead off about the fuel bills.'

You know the answer to all their troubles as well as we do. Inter-line that corrugated roof with inexpensive, easily-applied, everlasting Fibreglass heat insulation. Then Fred will stop perishin', Bert will stop beefing and the 'Guvnor' will stop biting. What's more, the installation of Fibreglass *will pay for itself* in less than three years!

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cones must be applied to glass cloth in solution, and then precured to drive off the solvent and to advance the resin to the laminating stage. The silicone laminating process is called " dry lay-up," to distinguish it from the " wet lay-up " techniques used with polyesters where resin is poured on glass cloth or mat right in the mould. Another point to be considered is that, at its laminating temperature, the viscosity of a silicone resin is approximately ten times that of a polyester resin. Finally, account must be taken of the fact that, like phenols and ureas, the silicones are condensation resins and give off volatile products during cure.

● *IMPROVED RESISTANCE-HEATING METHOD FOR STEEL BLANKS*

In the resistance heating of steel blanks for rolling or forging to temperatures of approximately 1000° C, it is of great importance to use good contact surfaces. It has proved practically impossible, especially in the case of supplying current to certain kinds of alloyed tool steel, to obtain a surface which, by being connected directly to contact materials such as copper, can carry the current intensity required for the heating process. The reason for the difficulty in resistance-heating alloyed tool steel is probably that point contact is obtained between the contact piece and the blank. The result is local heating and, as steel is not sufficiently conductive to cause cooling of the rapidly heated spot or spots, fusion will take place, and the blank will be ruined. A recent invention describes a means of overcoming this difficulty. The method proposed consists of the use of a plastic, deformable, electrically conductive contact material for the supply of current. This contact material is produced by pressing or sintering iron or other suitable metal powder in the form of plates. When applied to the surface of the blank this contact material, by deformation and spreading produced by the contact pressure, will provide a large contact surface for the passage of the electric current. The claim is made by the inventors that it is of no importance whether or not the contact surface of the blank is rough. This would appear to be of particular importance where the current is intended for the heating of blanks to be rolled, when for obvious reasons a rough end surface cannot be avoided.

● *IMPROVEMENTS IN FORGING AND EXTRUDING*

The increase in the size of presses now available for forming metals has introduced a number of problems. Thus, for instance, the selection and proper use of lubricants can be of great importance in obtaining full advantage of large presses in hot forging and extruding operations. In this respect an investigation of lubrication problems in connection with the forging and extrusion of aluminium and magnesium has yielded important information. It has been found that an increase in die temperature with respect to that of the aluminium or magnesium billet greatly improves the penetration of the metal into the die cavity. With the same graphite size and concentration and with similar spraying times, oil carriers of higher viscosity produced better die filling than carriers of lower viscosity. The size of the graphite particles appeared to have little influence upon the depth of penetration of the metal into the die cavities. Tetrafluorethylene resin primer, consisting of a low-viscosity dispersion in essentially a water medium of the type developed for use with steels, produced exceptionally good die filling in work with aluminium, when applied cold to dies and then heated to 700° F to cure the resin. However, if heated to 750° F, the lubricant gave off toxic fumes. This lubricant has also proved effective in forging magnesium if the dies are heated to at least 600° F to cure the resin. A satisfactory method of applying the resin to hot dies has not, however, as yet been found. Excellent die filling was achieved with aluminium billets which were first etched in sodium hydroxide and dipped in a water suspension of colloidal graphite before heating. They were then forged with conventional lubricants on the dies. Dipping magnesium billets with slightly roughened surfaces into an aqueous suspension of colloidal graphite before heating and then forging them with conventional lubricants greatly improves the filling of the die.

● *MEASUREMENT OF WATER VELOCITY BY ULTRASONICS*

A special phase-measurement circuit has been developed for incorporation in a subsurface water-velocity meter, which is based on the use of ultrasonic wave transmission between a transducer and a receiver. The complete instrument consists of two units, one of which floats in the stream, while the other rests upon the bottom of the water body. The floating part, which is of torpedo shape, carries on its outside two transducers and contains a phase-measuring circuit, a magnetic compass, and a transfer relay. The other unit, resting on the bottom of the stream, is a large drum which contains a storage battery, power supplies, control circuits, indicators, and a recording camera. When the apparatus is in use, the large drum rests on the bottom of the stream and acts as an anchor. One end of a steel cable is attached to the drum, while the other end is supported at the water surface by a buoy, the torpedo being attached to the cable at a point corresponding with the desired depth of measurement. An eight-conductor cable also runs between the drum and the torpedo. The latter is mounted in a gimbal, so that it is free to align itself with the water current. The water-flow velocity is measured by observing and evaluating

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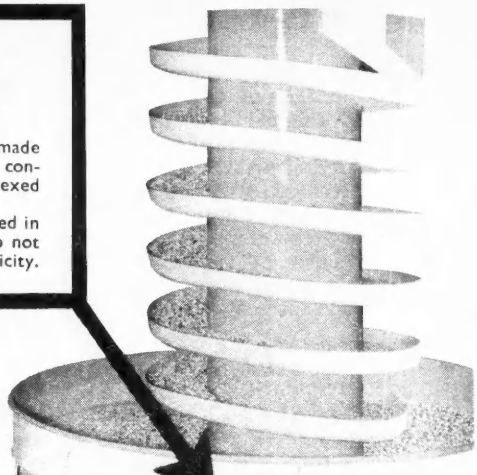

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the phase difference between the transmitted and the received ultrasonic beam signal. For the purpose of measuring this phase difference the special phase meter circuit mentioned is employed. The control equipment is designed to turn on the unit every thirty minutes, for an interval of time sufficient to take one set of readings. An 8-mm motion-picture camera, with its shutter removed and its mechanism modified for single-frame film advance, is mounted in the unit to photograph the phase meter and other instrument readings. Exposures are made by flashing a small lamp. The entire equipment is contained in the submerged casing.

● *NEW STEEL-INGOT HEATING PROCESS*

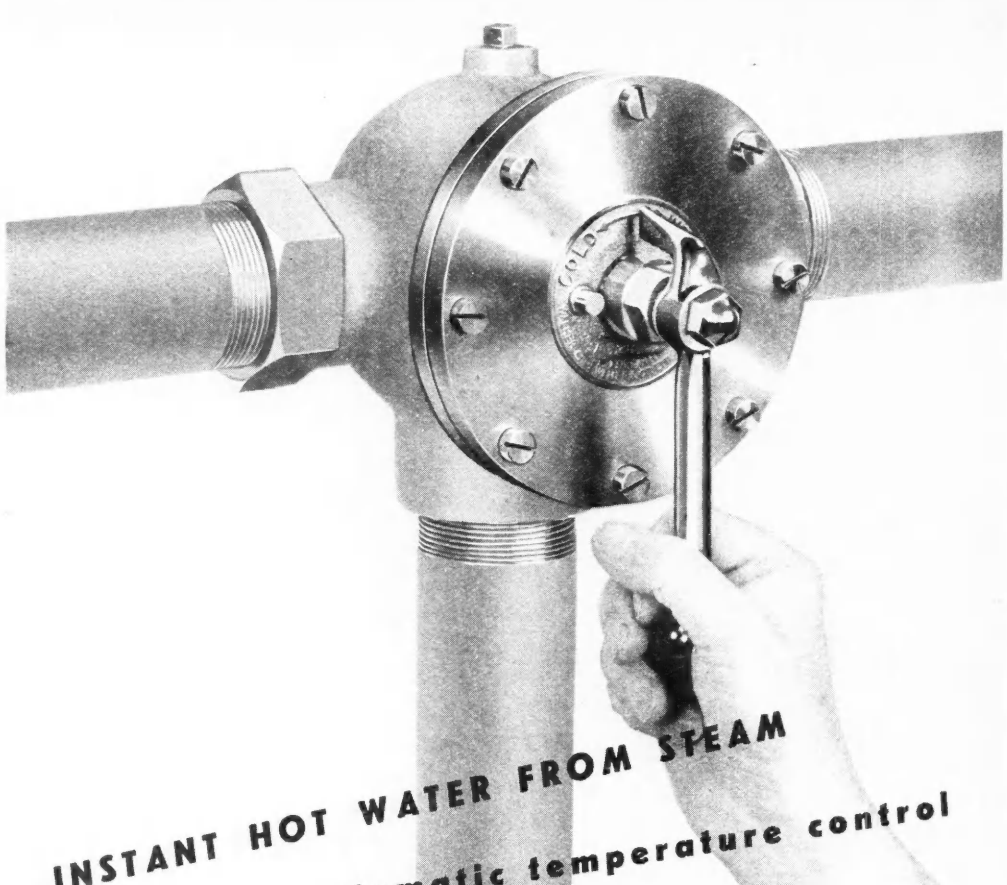
The recent introduction of electric induction heating for the heating of steel ingots in steel-plant practice is reported to shorten ingot heating time by approximately 75% and to increase production by some 30%. The induction heating unit used for the heating of ingots comprises a series of large water-cooled copper coils set in refractory blocks, placed end to end to form a tunnel. The ingots are fed in at one end of the tunnel, pushed slowly through the tunnel, and emerge at the other end at a temperature of approximately 2300° F, ready for rolling into finished steel bars. It is stated that the heat produced in the ingots is so intense that, if they were left in the furnace for even half a minute too long, they would melt. Delicate balancing of the very large magnetic forces created by the induction heating process is said to be of the greatest importance, since these forces would be large enough to shoot the red-hot ingots out of the tunnel. The heating tunnel is divided into two portions, the first of which operates at mains frequency. In the second half, where maximum heat is obtained, a frequency of 600 cps is used, provided by a 5700-hp motor generator. Furnace operation is controlled from a central pulpit placed directly over the tunnel, where one man supervises the controls. Instruments are provided to indicate power consumption, heat, feed rate, cooling-water supply, temperature, etc.

● *SUPPRESSION OF BURNER OSCILLATIONS*

Combustion systems often generate acoustic oscillations, which not only may be annoying, but at times may become so violent as to damage or destroy the equipment. It is difficult, if not impossible, to design a combustion system in such a way that no oscillations can occur, particularly as the exact mechanisms of oscillation generation are not known for many of the types of oscillations that can occur. It is therefore interesting to note that a recent research report gives details of tests conducted on the suppression of burner oscillations by means of acoustic damper devices. Several positive conclusions were derived, and these may help to quieten particular combustion installations, or may be of value in preventing waste of effort in trying ineffectual methods. The effectiveness of a quarter-tube was found to be critically dependent on length, but relatively insensitive to location, as long as the tube is placed in the region of the pressure antinode. Similarly, the effectiveness of a Helmholtz resonator depends critically on volume for a particular neck, but it is quite insensitive to location. In neither case does the suppressor have to be placed near the particular antinode where energy is fed into the oscillation. The degree of suppression obtained was found to be approximately proportional to the cross-sectional area of the tube. As the report states, the same conclusion appears to be warranted with regard to the cross-sectional area of the throat of a Helmholtz resonator. Almost complete suppression was obtained by drilling a hole in the side of the tube at a location within 10% of a wavelength from a pressure antinode. It was found that the diameter of the hole need not be greater than approximately one-tenth to one-fifteenth of the diameter of the combustion chamber, but it should be greater than the wall thickness for optimum suppression.

● *RE-INJECTION OF FLY-ASH IN SPREADER-STOKER FIRING*

In spreader-stoker firing the problem of fly-ash collection and disposal is of considerable import, especially as the carry-over is predominantly in the form of carbon. In order to avoid this loss of combustible, it has therefore been proposed to utilize the well-known principle of collecting the fly-ash and re-injecting it into the furnace for final combustion. A recent example of such an installation is that provided for a spreader-stoker-fired boiler operating at a rate of 80,000 lb of steam per hour. In this case a gravity re-injection system has proved its merits. The ash collected from the dust collector and economizer dust hoppers falls through ducts to a dust valve of special design into another hopper at the rear of the boiler, just above the level of the forward-moving travelling grate. From this hopper the fly-ash flows by gravity through pipes onto the rear end of the stoker, so that the carbon contents of the fly-ash are burned on the grate as it moves forward. Test results obtained when disposing of the fly-ash outside the boiler showed that, of all the carbon fed into the furnace, 6·8% passed out of the furnace in the fly-ash. Of this 1·5% was collected in the hopper underneath the last pass of the bent-tube boiler, 2·9% was collected in the hopper underneath the economizer, 2·2% in the dust collector, and only 0·2% went up the stack. In another test the material from the hoppers under the last pass of the boiler and the economizer respectively was re-injected into the furnace in a conventional manner by blowing, discarding the material from the collector.



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Carry-over from the furnace amounted to 10·5%, and a recovery efficiency of 16% by re-injection was achieved. When returning by gravity all the material collected, recovery of combustible was 6·6%, with a recovery efficiency of 97%, while the total carbon loss was less than 0·1%.

● *STRESS FATIGUE OF STEEL*

Several research papers of recent date make important contributions to the analysis of problems involved in assessing the stress fatigue of steel. One of these papers presents a simple theoretical model for predicting the change in endurance limit resulting from the accumulation of overstressing cycles at moderate levels of overstress and for moderate degrees of fatigue damage. The author states that it is reasonable to assume that fatigue damage occurring prior to the formation of a visible crack is equivalent to an increase in a "stress-concentration factor" associated with the particular defect in the specimen which will form the fatigue nucleus. The application of simple notch-factor concepts and the use of an empirical formula for the *S-N* curve for steel resulted in an equation for predicting the change in this curve when specimens are subjected to overstressing histories producing moderate amounts of fatigue damage. In another paper fatigue specimens are considered in which the stress amplitude is constant with respect to time but falls off parabolically along the length of the specimen from the point of maximum stress. From assumptions regarding the local variability in the strength of the material, equations are derived relating the scatter in cycles to failure to the scatter in position of failure. The effect of specimen size is determined for these two types of scatter, as well as for the average life.

● *RAPID PROCESS FOR THE PRECISION CASTING OF METALS*

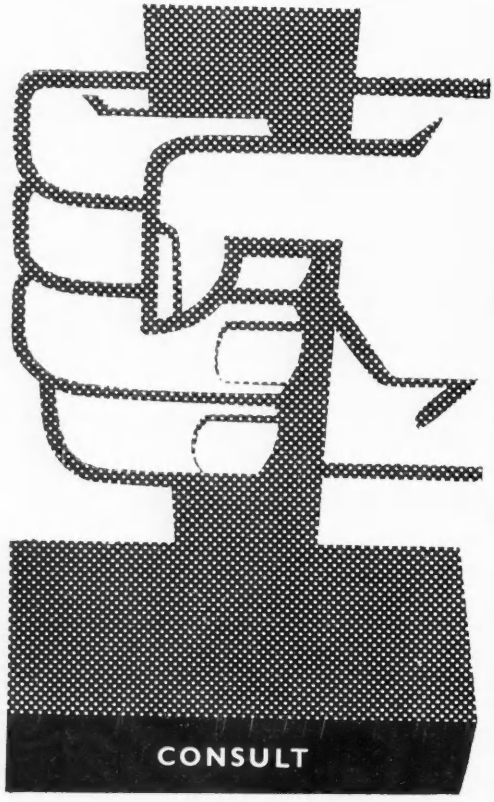
A rapid, economical method for the precision casting of metals through the use of glass moulds has been developed. This process has been especially devised for work with high-temperature alloys and is claimed to assure an excellent surface finish and the close dimensional control required in precision casting. Since the moulds can be used at extremely high temperatures, the design of fine detail and close control of the metallurgical structure are possible. It is reported that, in the experimental production of jet-engine blades and vanes, 90% of the finished castings have met precision standards of surface finish. The new process, designated "Glascast," eliminates the use of the precoat step in investment casting and the undesirable cracking and spalling which necessitates the rejection of a high percentage of castings. The glass powder used is essentially a silica glass, 96% pure, which is mixed with water to produce a casting slip. When poured into a porous plaster form, the slip builds up into a glassy shell, which is dried, removed from the plaster, and fired. The mould is then ready for use without any further treatment. Castings produced by the method are said to have blemish-free surfaces with a finish of better than 40 micro-inches, and do not require any further conditioning. The mould material has high chemical stability and does not react with the metal or its oxides to cause surface imperfections. Accurate control of grain size is thus possible, even at metal-pouring temperatures as high as 3200 F. Close dimensional control of the castings is assured, because the vitreous glass powder has extremely low thermal expansion, avoiding the abrupt volumetric changes which are typical of foundry sands. Tolerances of 0·005 inch per inch can readily be obtained.

● *NEW ENGINE-OPERATION ANALYSER*

Faults in the ignition system of a spark-ignited gas engine are among the most difficult to diagnose. Furthermore, it is not often known whether or not the system is faulty. The inspection and test of the circuit and its parts under static conditions, i.e., when the engine is not running, sometimes fail to reveal faults; when, however, the engine is running under load, its performance and efficiency may be below standard. This condition is, of course, brought about by the very nature of the equipment. The mechanical working parts of an ignition system, such as the magneto and distributor, are so completely enclosed in housings that visual observation under operating conditions is impossible and, short of elaborate laboratory equipment, the electrical phenomena occurring in the circuit cannot be observed. It is stated that an instrument has been developed which makes it possible to find such hidden faults rapidly and with comparative ease. This instrument, termed a cathode-ray engine analyser, is completely portable and displays on the face of the cathode-ray tube a picture of the entire ignition process as it takes place. Basically, the analyser is an oscilloscope which is automatically synchronized to the position of the engine crankshaft. It is also possible to carry the instrument in the vehicle itself and to check engine performance under actual operating conditions. The analyser is said to detect virtually all ignition-system troubles, including such common faults as spark-plug fouling and misfiring, open or short-circuited plugs, defective wiring and switches, worn distributor cam and shaft bearings, and defective coils, condensers, or magnetos.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

For pressure die-castings



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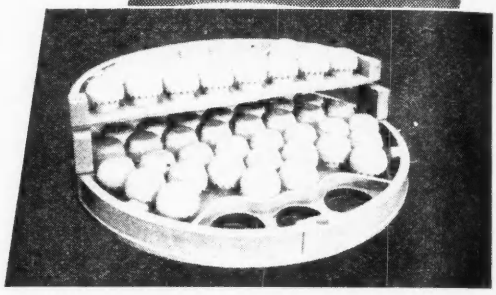
Stoneware Bubble-caps



The Bubble-caps and Plates shown are in "Heatware" grade acid-resisting Stoneware. These plates are made up to 5 ft. diameter and in the larger sizes, plates are formed in halves. A special feature is that the caps are integral with the plates. Columns of iron or steel are lined with either one-piece Stoneware sections or Stoneware tiles, and loose Bubble-caps of Stoneware can be supplied for inserting in existing columns if required.

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